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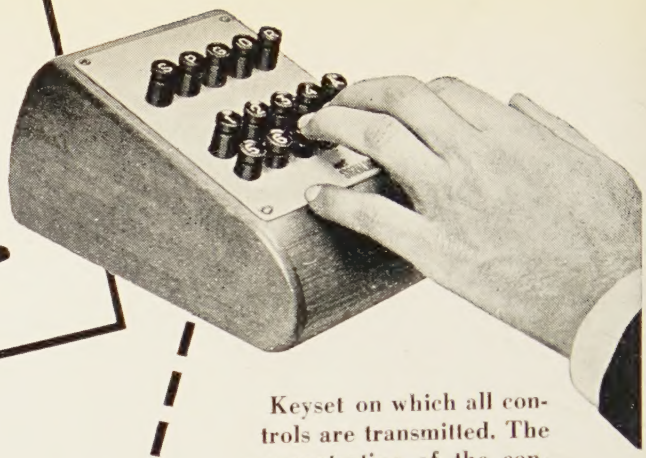

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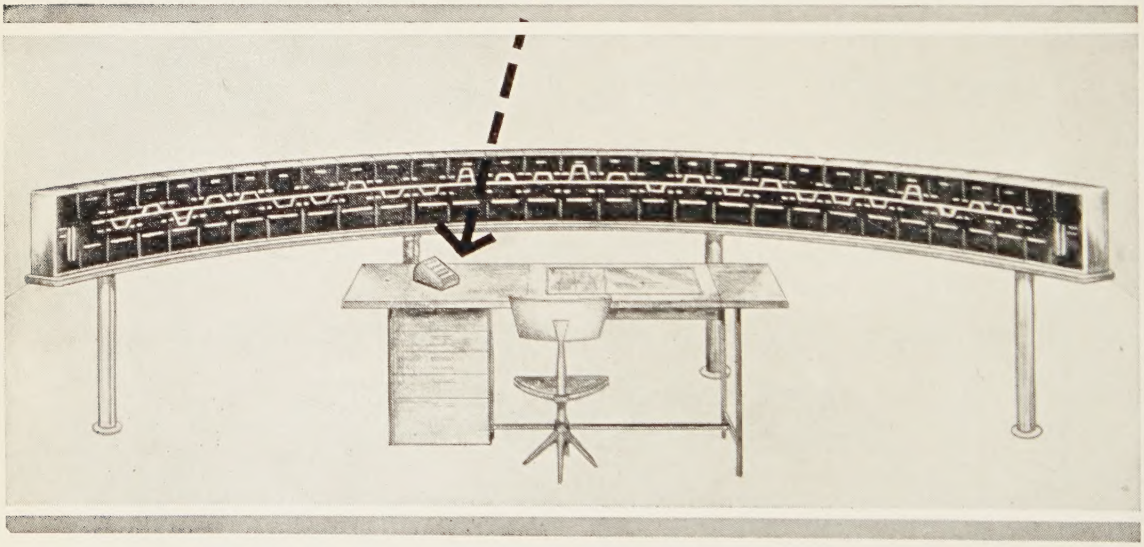

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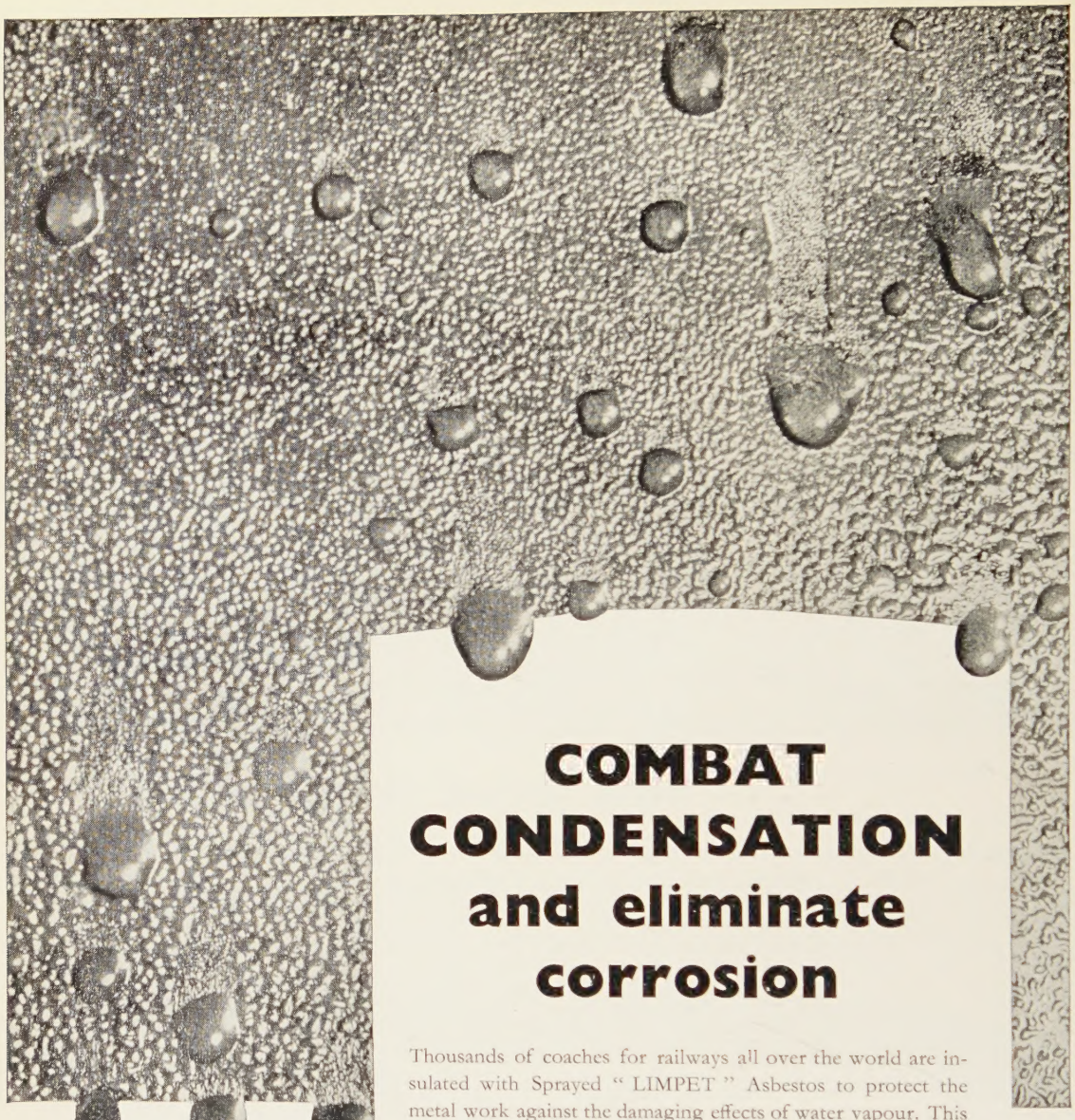

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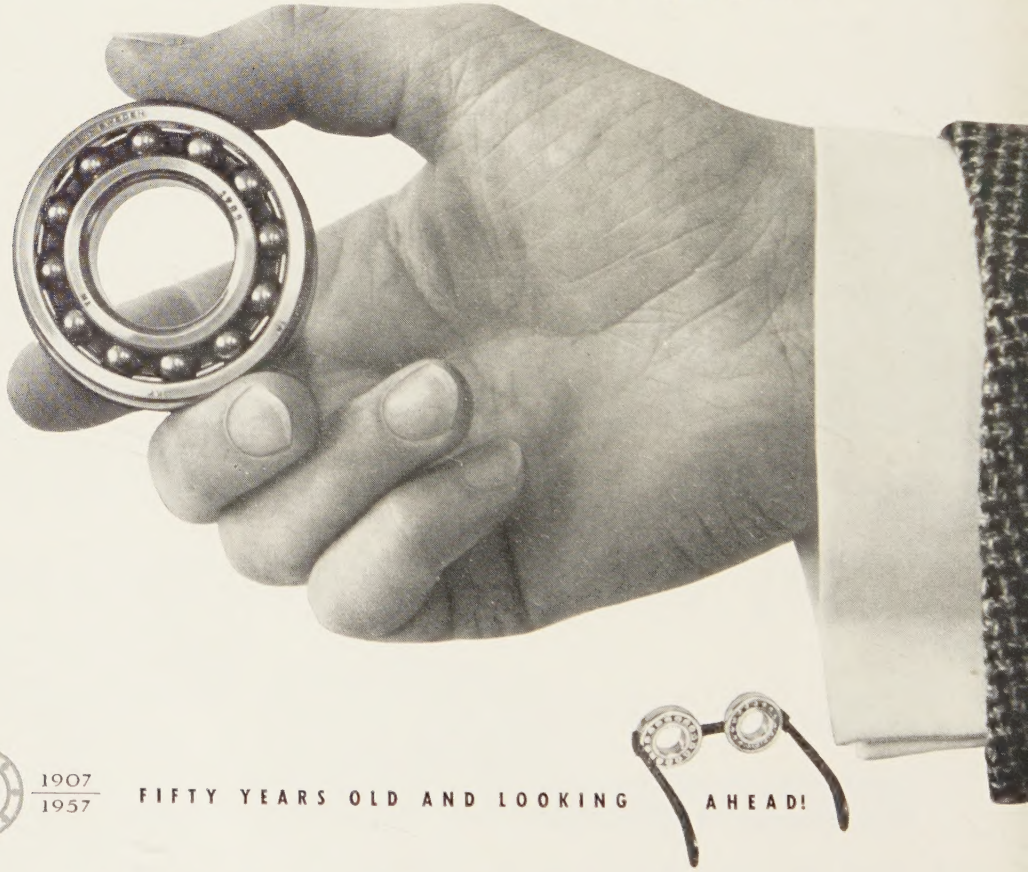

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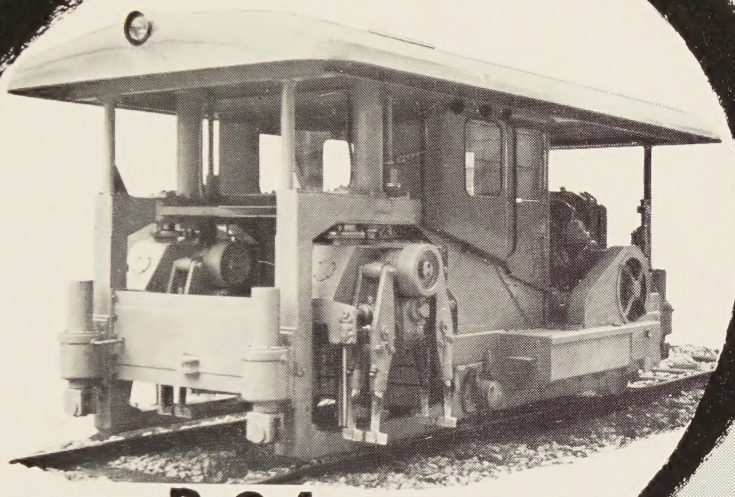

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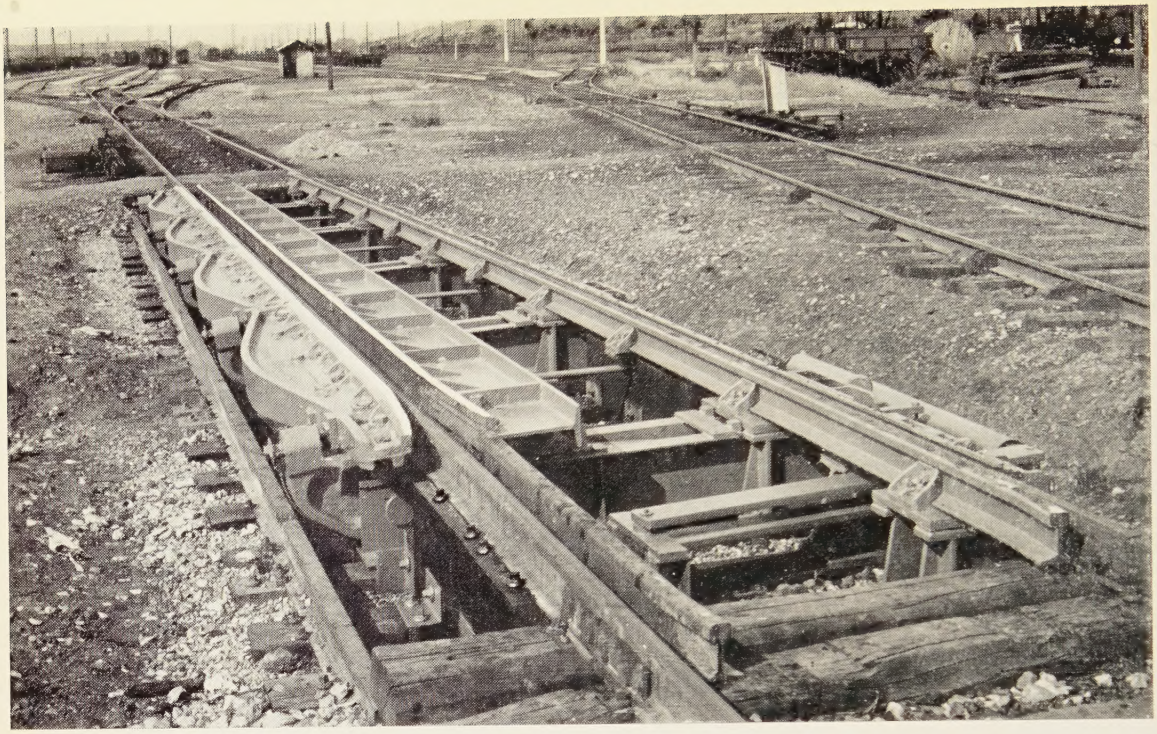

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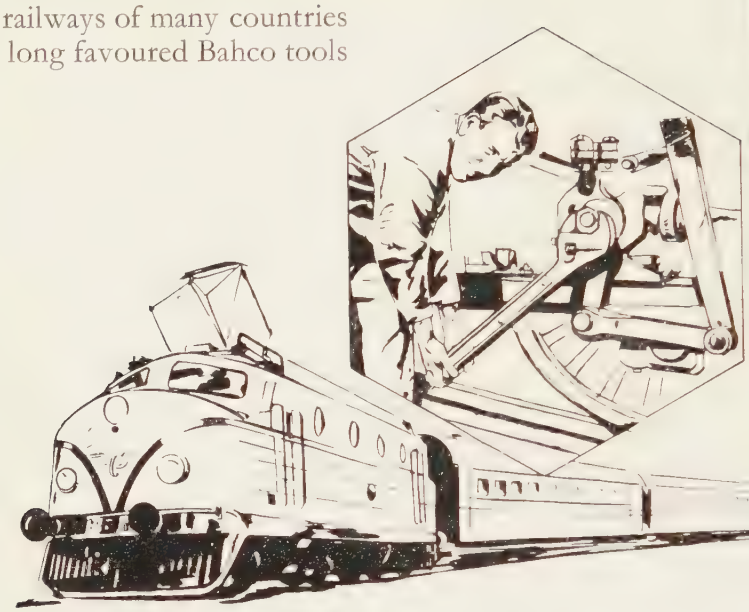

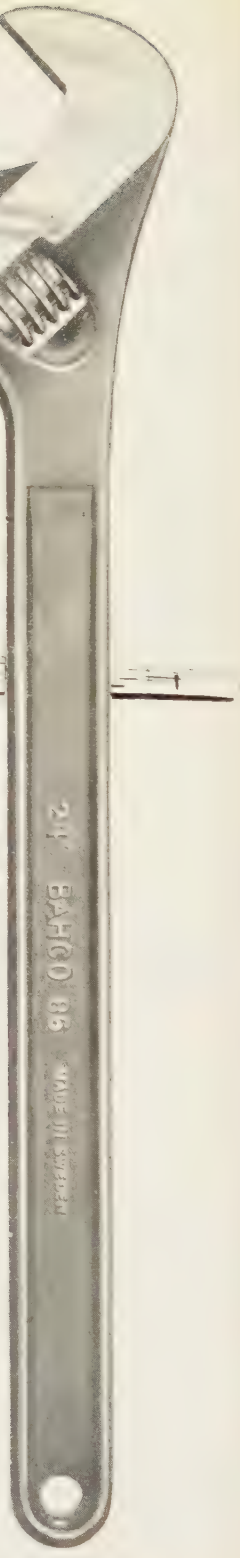

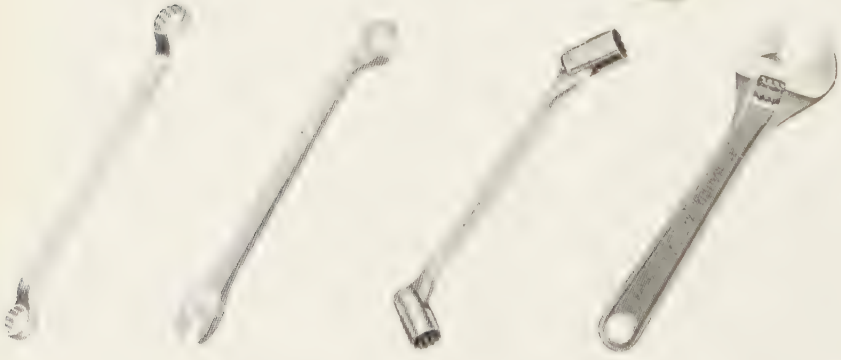

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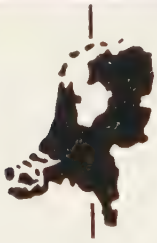

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BULLETIN
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[625 .143 .3 (43) & 625 .17 (43)]

Ultrasonic examination of rails, and the testing car of the German Federal Railways,

by Dr. phil. Erich MARTIN and Dr. rec. nat. Dipl.-Ing. Karl WERNER, Minden.

(*Eisenbahntechnische Rundschau*, No. 12, December 1956.)

Ultrasonic inspection has, in recent years, been found to be an exceptionnally suitable method for detecting flaws in rails located in operating tracks. The increase in traffic safety afforded by this type of rail testing will depend on the thoroughness and speed with which railway lines are examined for failures not discernible by visual inspection. Therefore, the authors designed a manually operated test set, units of which were supplied to all regions of the German Federal Railways. The good results achieved with the impulse-echo method led to the construction of an ultrasonic rail inspection car for the purpose of extending and accelerating the inspection work. The article contains detailed information about the system applied, its improvements, the results obtained by testing 2 000 kilometres of line and gives a complete description of this inspection car and its equipment.

It has already been pointed out on many occasions that it is possible to detect flaws in rails by means of ultrasonics. It is known from specialised publications that for the purpose of examining rails for flaws, both the frequency modulation method and the pulse echo method are in use (1).

With the *frequency modulation system*, the ultrasonic waves, changing their frequency periodically by a predetermined amount, known as frequency shifts, are made to enter the rail from the running surface and to penetrate into the interior of the rail. If the rail is free from defects, the waves are reflected from the underside of the rail and return to the running surface. While the wave is on the way, the frequency of the outgoing waves has changed compared with that of the reflected ones. By a judicious choice of the frequency shift and the frequency of the modulation (« frequency of frequency change »), the resulting beat frequency may be made audible. After demodulation, an audible oscillation is produced, i.e. a sound, with a pitch depending on the depth of the rail. If there is, in the longitudinal direction of the

(1) (*a*) « Railway Age », 3rd December, 1949.
(*b*) E. MARTIN and K. WERNER : « Prüfung verwickelt geformter Teile mit Überschall » (« Testing of awkwardly shaped components by means of ultrasonics »), « Archiv für das Eisenhüttenwesen », 24 (1953), No. 9/10, pages 411-422.
(*c*) E. MARTIN and K. WERNER : « Werkstoffprüfung mit Ultraschall, insbesondere Prüfung von Schweissungen » (« Ultrasonic testing of materials, especially welds »), « Schweissen und Schneiden », No. 5, 1953. Special number, pages 74-81.

rail, a horizontal fissure in the material, the shorter transit time of the wave must, in principle, produce a sound of a lower pitch. In practice, it is difficult to recognize the pitch of the sound because the waves travel, not once, but several times from one surface to the other and are, incidentally, also reflected by other surfaces, e.g. those of the rail head. In consequence, there is a mixture of beat frequencies which the car can hardly distinguish. In addition, with the apparatus normally used, the modulation frequency is likewise audible.

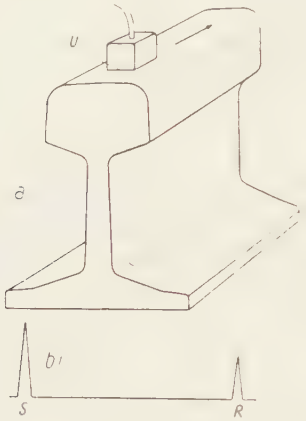


Fig. 1. — Diagrammatic representation of the pulse-echo method :

(*a*) rail with vertical probe on running surface;

(*b*) oscillograph with transmission pulse S and echo R.

The fact remains, however, that a hole or flaw in the rail causes a perceptible modification in the pitch of the audible note. Apart from the acoustical indication, these devices often provide an amplitude indication by means of a pointer and scale instrument. With this method, it is possible to detect longitudinal horizontal or oblique flaws and to estimate the longitudinal extent of these flaws. Tests have shown that it is also possible, in certain cases, to detect fractures in the transverse direction, especially if these, as is the case with rail fractures, deviate slightly from the vertical. It is not possible to determine at what depth the flaws are to be found or what parts of the cross-section are affected by the flaw.

With the *pulse-echo method,* one transmits to the rail, not continuous waves, but ultrasonic pulses at equal time intervals of between 1 and 10 milliseconds. In certain special cases, these pulses may also be transmitted to the rail, not from the running

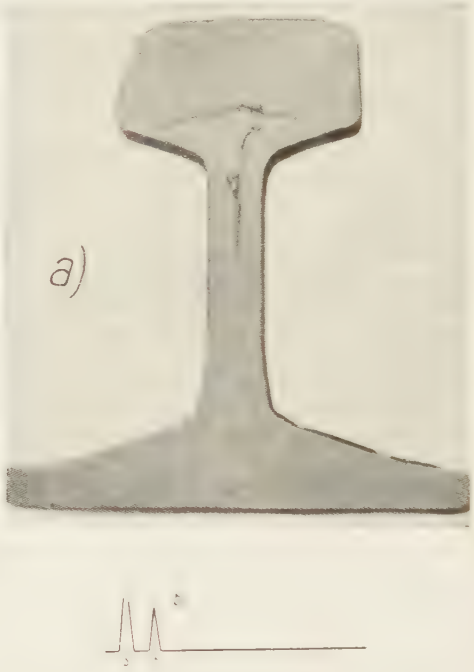


Fig. 2. — Horizontal flaw running lengthwise in head of rail :

(*a*) cross-section of rail;

(*b*) diagrammatic sketch of oscillograph with transmission pulse S and flaw echo F.

surface, but from the side faces of the rail head or web, or from the top or bottom surface of the rail foot. If the probe head is moved in the vertical position, along the centre line of the rail top, the ultrasonic pulses transmitted to the rail by the piezo-electric transmitter are reflected from the underside of the foot and returned to the

same oscillator where they are converted into pulsating electric charges and, after amplification, directed to the vertical deflecting plates of the cathode ray tube. To the horizontal plates of this tube is applied an electric voltage which is synchronized with each outgoing pulse and increases proportionally with time (2). Due to the continual repetition of the transmission and reception cycle, a curve appears on the screen which, to the human eye, appears to be stationary. The ordinates of this curve indicate the amplitudes of the ultrasonic waves received, whilst the abscissae indicate their transit times. As the speed of sound in steel is constant, the abscissa can be directly measured in terms of distance covered, instead of transit times, so that it is possible to read off, directly from the fluorescent screen, the distance of the reflecting point.

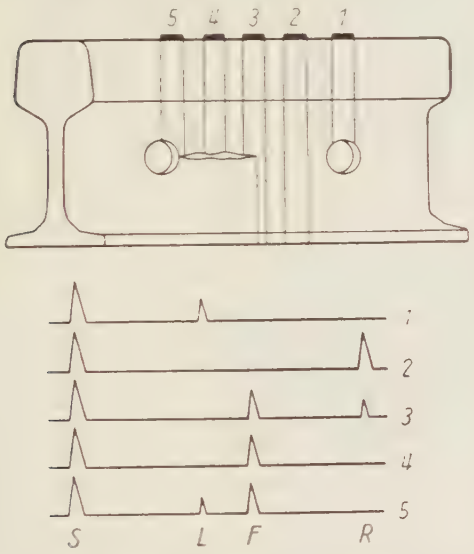


Fig. 3. — Diagram showing an incipient horizontal flaw originating at a fish bolt hole, and oscillographs obtained at different positions of the probe.

In contrast with the frequency modulation method, the pulse echo method provides *accurate* information of the position and orientation of the flaws in the rail so that the nature of the defect can be clearly identified. For instance, transverse fractures in the rail head can be reliably detected as such, even if they are perfectly vertical. Such flaws cannot be detected with simple devices of the normal type which work on the frequency modulation principle and are used as portable outfit by certain railway administrations. With the pulse echo method, it is also possible to indicate, with equal precision, the extent of horizontal longitudinal flaws and, by way of close approximation, the part of the cross-section over which the transverse flaws extend. In this way, it is possible to predict whether the flaw is likely to lead to an early failure so that the rail must be replaced immediately, or whether it is safe to leave the rail in position subject to periodical observations, or even to leave it in service without further special observation because experience has shown that the kind of flaw concerned does not lead to rail failure.

Because of its inherent potentialities the German Federal Railways have decided to apply the pulse echo method for large-scale ultrasonic testing. We propose to show, by means of some typical examples, how it is possible, with the aid of this method, to detect horizontal and oblique flaws by means of vertical sounding and transverse flaws by means of sounding at an angle to the vertical. If the probe head is moved along the centre line of the running surface in the longitudinal direction of a flawless rail (fig. 1*a*), the screen of the oscillograph will show a curve of the kind reproduced in figure 1*b*. The transmission pulse S corresponds to the running surface on which the ultrasonic probe head U is placed, while the bottom echo R corresponds to the underside of the rail. If there happens to be a horizontal flaw in the rail head (fig. 2*a*), which may, for instance, be caused

(2) Details about the ultrasonic testing method are given by Martin in « Das Materialprüfwesen im Dienste der Fahrzeugerhaltung » (« The testing of materials as an aid to rolling stock maintenance »), « Eisenbahntechnische Rundschau », 1953, No. 10; see in particular pages 514-519.

by an incipient fissure or a slag inclusion, one obtains an oscillograph of the kind illustrated in figure 2*b*. The beam of ultrasonic waves transmitted to the rail from the running surface is reflected by the defect, and the flaw echo is shown at its exact distance from the transmission pulse S, i.e. at a shorter distance from it than the bottom echo. The valve shown on the scale of the fluorescent screen indicates the distance of the flaw from the running surface.

of the fraction of the ultrasonic beam reflected from the surface of the crack. When the pulsator is exclusively above the crack, i.e. in position 4, the oscillograph will exclusively show the flaw echo. Finally, in position 5, above the crack and the fish bolt hole, the flaw echo and that of the fish bolt hole appear together (oscillograph No. 5).

If the flaw originating at the fish bolt hole is oblique, e.g. as shown in figure 4, and if the surface of the crack is smooth,

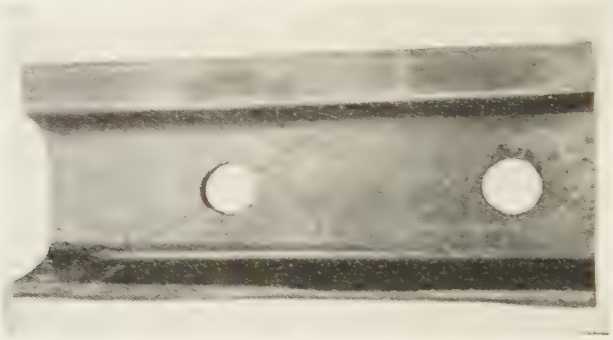


Fig. 4. — Incipient cracks running obliquely from fish bolt hole.

If the test is applied to a fish-plated rail joint in order to detect incipient fractions originating at the fish bolt holes, one obtains oscillographs of the kind shown diagrammatically in figure 3. When the pulsator happens to be in position 1, in the centre line of the running surface just above the fish bolt hole, there appears, in oscillograph No. 1, in addition to the transmission pulse the echo of the fish bolt hole due to the reflection of the beam from the top of the hole. When the pulsator is in position 2, above the sound part of the rail, the transmission pulse will be accompanied by the bottom echo from the underside of the foot. In position 3, when the pulsator is partly above sound metal and partly above the horizontal flaw, both the flaw echo reflected by the surface of the crack and the bottom echo are apparent. Their relative heights provide a measure

the beam is diverted in accordance with the law of reflection. In this case, little or none of the beam will return to the pulsator, and the flaw echo produced by it on the screen is non-existent or very weak. The bottom echo, too, is missing. These indications are typical for an oblique flaw. In practice, the ends of the oblique cracks themselves give rise to recognizable echoes, due to the ultrasonic waves reflected from the edge of the crack so that, in most cases, it is possible to indicate the direction of the oblique flaw (inclination upwards or downwards).

It is not possible, or at least very difficult, to detect by means of vertical injection of ultrasonic waves from the running surface any transverse cracks such as those originating from skid flats repaired by welding (fig. 5), or kidney fractures caused by flakes (fig. 6). For this purpose, it is

Fig. 5. — Fatigue fracture originating at a shelled flat reconditioned by welding

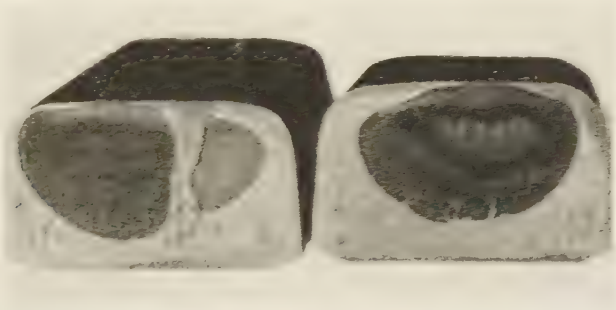


Fig. 6. — Kidney fractures

necessary to introduce into the rail « plane waves » such as those which the present authors were the first to apply to vehicle axles (3). The ultrasonic pulsator is mount-

(3) E. Martin. « Oberschallmessung von Achsen von Schienenfahrzeugen ». « Ultrasonic testing of railway vehicle axles ». « Stahl und Eisen » 72, (1952), No. 4, pages 176-185. The method is also described in the articles referred to in footnotes 1 (*b*) and 1 (*c*).

the smaller become the amplitude of the ultra-sound waves emitted as well as the sensitivity of the reception of the ultra-sound waves. If the pulsator, consisting of the oscillator and the plastic wedge, is moved along the test piece surface in the direction of the flaw (or, as in this case, the small hole), i.e. in the present case from bottom to top, the ultrasonic beam will, in position (*c*), encounter the hole with a small amplitude. One obtains a relative measure of the amplitude from the radiation segment between the centre of the plate and the club-shaped curve. For the reason explained above, the amplitude reflected in the direction of incidence is received with a comparatively low sensitivity. In consequence, the flaw echo on the fluorescent screen is still very small while the distance of this flaw echo is great, corresponding to the great length of the path (oscillograph *c*). In position (*b*), the ultrasonic waves encounter the flaw with their maximum amplitude. Here, the echo reaches its maximum height and lies closer to the transmission pulse. When the pulsator continues to move on the position (*a*), the beams again encounter the flaw with a small amplitude. The flaw echo becomes smaller and, at the same time, lies still closer to the transmission pulse, as the distance covered by the beam is shortened. When the pulsator is moved at a constant speed along the surface of the rail in the direction of a flaw, an echo should therefore be received at a fairly great distance from the flaw. This echo must increase

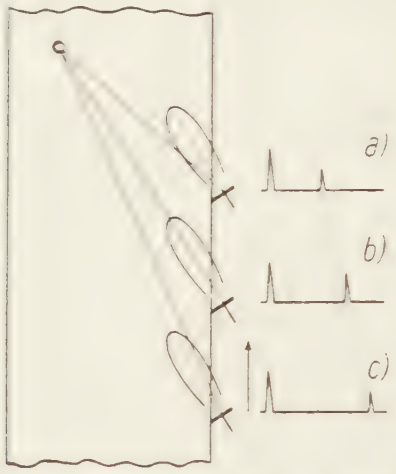


Fig. 7. — Diagram illustrating the shifting of the pulse echoes during the movement of the oblique probe.

Fig. 8. — « USPG » ultrasonic rail testing apparatus of the German Federal Railways.

until it reaches a maximum; it will decrease again when the pulsator continues to approach the flaw, and will finally disappear. It has been found in practice that it is possible to estimate the size of a transverse flaw from the length of the « moving zone » of the flaw echo and the maximum height of the echo.

the web of the rail. These incipient fractures at the bolt holes account for about 60 per cent of all rail fractures. Since, some years ago, two of these fractures gave rise to grave accidents, the authors designed, in 1953, an ultrasonic rail testing apparatus which has simplified the examination of fishplated joints.

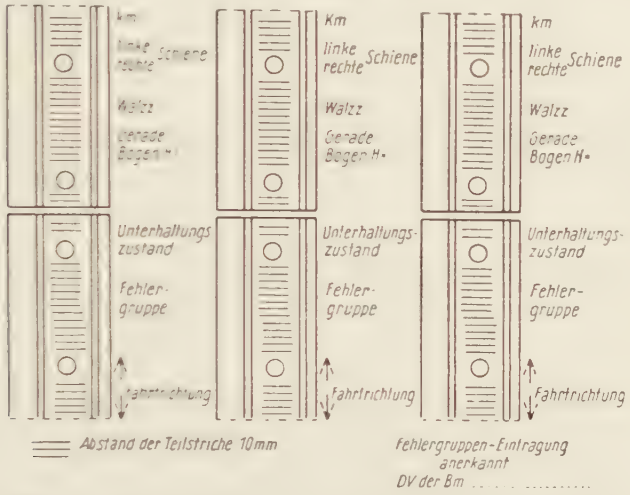


Fig. 9. — Report sheet for recording results of ultrasonic tests. Two of these specimens, here shown in half-size, are arranged one above the other so as to form the DIN A 4 standard size.

N. B. — Linke rechte Schiene = left/right rail. — Walzz = mill mark. — Gerade = straight track. — Bogen H = curved track, radius. — Unterhaltungszustand = condition. — Fehlergruppe = flaw group. — Fahrtrichtung = direction of travel. — Abstand der Teilstriche = division spacing. — Fehlergruppen-Eintragung anerkannt = flaw group assignment approved. — DV der Bm = Foreman, maintenance section.

ULTRA-SONIC RAIL TESTING DEVICE (U. S. P. G.) FOR THE DETECTION OF FLAWS IN FISHPLATED RAIL JOINTS.

1. Form, application and performance of the device.

Ultrasonic testing by means of vertical probes is applied to the examination of fishplated joints where the defects mainly consist of cracks which originate from the holes of the fishplate bolts and extent horizontally or in an oblique direction into

The apparatus (fig. 8) is designed in the form of a trolley running on one rail and provided with a hinged outrigger which is fitted with a guide roller running on the other rail. It consists of a current generator with automatic voltage regulation, a voltmeter and an ammeter (seen on the right-hand side of the illustration), an ordinary commercial-type ultrasonic testing device with pulse transmitter, amplifier, time-base unit, cathode ray tube and accessories housed in a pivoted rotary container (on the left and in the foreground of the illus-

tration) and of the probe rod proper which is conducted by hand and contains the ultrasonic generators. A sun-protection screen placed in front of the fluorescent screen permits the observation of the latter even in brightest sunlight. In addition, the frame carries a tank for the coupling fluid which ensures the passage, without air gap, of the ultrasonic waves between the apparatus and the rail. The unit can be moved along the rail with ease and can moving the pulsator slowly along the rail surface. The irregularity is recorded on a report sheet (fig. 9), with indication of the kilometre post, year of manufacture, and maker's name, as well as its position in straight or curved track, or on the inner or outer rail. These data provide valuable statistics. The flaws found are classified in three groups according to their extent and their position (fig. 10). The first group comprises those flaws which have

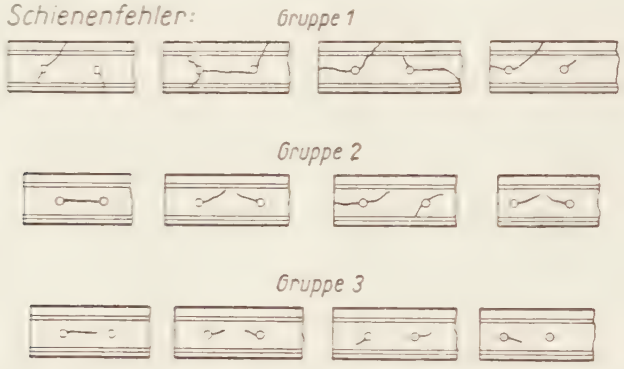


Fig. 10. — Group classification of incipient fractures emanating from fish bolt holes.
Schienenfehler = rail flaws. — Gruppe = Group.

be lifted off the rails by two men by folding the outrigger back. The lower end of the probe rod holds the oscillating unit which is cardan-mounted so that it finds its own position in contact with the rail. The unit is guided along the centre line of the running surface by means of adjustable guide rollers. The outlet pipes of the coupling fluid are mounted on the probe rod and are controlled from the hand grip of the rod by means of a flexible cable. The rod can be moved without effort and can be pushed along the rail in such a way that the operator can devote all his attention to the screen. If the oscillograph shows a flaw echo of the kind reproduced in figure 3, or if the bottom echo disappears, this means that a horizontal or oblique crack is present. The length of the crack can be accurately ascertained by already penetrated the head or foot of the rail and which call for the immediate replacement of the rail. Group 2 comprises flaws which extend from one fish bolt hole to the next or run along the web from this hole to the head or foot. The rails with such flaws may, subject to observation and re-checks at frequent intervals, remain in service until they can be replaced without giving rise to operating difficulties. The third group of flaws includes the small incipient cracks where the rails can be allowed to remain in service until the next periodical track overhaul is due.

Each Region of the German Federal Railways is equipped with units of this kind. With their aid, all the lines of the German Federal Railways have already been examined several times over, and each passage over the main lines involves the checking

of about 2 million rail joints. Due to this checking, there were practically no failures of rail joints in operation in 1955 whilst, in the year preceding the introduction of the checking system, there had been about 5 000 of such failures. In view of this result, the procedure can well be said to have stood the test to the fullest satisfaction. Not only has the safety of operation been considerably increased; it must also be pointed out that the replacement of defective rails can now take place without dislocation of traffic.

2. Comparison with other test procedures.

After this comparatively simple testing device had already shown excellent results in the checking of rail joints, a comparison was arranged with other types of rail testing equipment. For this purpose, trials were carried out, on a railway line outside Germany, with a test wagon permitting the detection of rail flaws by means of electromagnetic induction; an ultrasonic detector working on the principle of frequency modulation, and the flaw detector of the German Federal Railways described above which works with the pulse echo method. These trials comprised not only the rail joints but the rails over their whole length. The German apparatus was fitted with a special probe rod with three probing units, one being vertical and the other two oblique. Subsequently, tests were carried out with the aid of the two last-named detectors on a great number of pieces of defective rails supplied by various railway administrations for the purpose of determining the position, type and extent of the flaws.

The testing device developed by the authors was the subject of a report of an international committee of experts which reads as follows :

Working principle :

An ultrasonic apparatus of the pulse echo type. The device works with several frequencies, and the reflected waves are observed on the screen of a cathode ray oscillograph.

Range of application :

With this device, it is possible to detect flaws in the head, the web and the central portion of the foot of the rail as well as transverse flaws in the foot of the rail at welds. Flaws can be detected along the length of the rails, at fishplated joints and at welded joints.

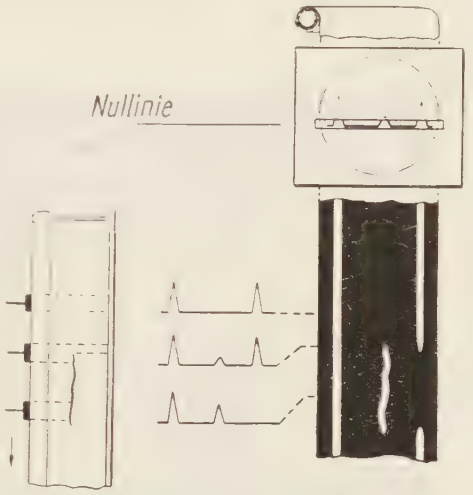


Fig. 11. — Diagram illustrating the flaw recording method based on the masking of the screen.

Nullinie = reference line.

Moreover, if a more precise or more complete examination is required, the device can be used to test the entire cross-section of the rail.

The structure of the rail (heat-treated or non-heat-treated rails) has no influence on the detection of the flaws.

The presence of rail corrugations has no detrimental effect.

Sensitivity :

With the installation of an electronic amplifier, the sensitivity of the device can be controlled so that it is easy to detect flaws whose projection on the plane parallel to the piece of rail is less than 5 per cent of the section of the head.

The apparatus has a high sensitivity and permits the carrying out of tests on a large scale. Moreover, due to the recording of the cathode oscillograph, the type and extent of the flaw can be accurately determined while the orientation and position of the flaw can be determined with sufficient accuracy to furnish the results required for decisions regarding the repair or replacement of the track.

is somewhat reduced if there is a higher proportion of defective joints. The following performances were obtained in the course of trials carried out on the lines of the Belgian National Railways :

5.3 km pr. day on track with rails of 27 m length (428 joints, including 128 defective).

5.0 km pr. day on track with rails of 18 m length (556 joints, including 48 defective).

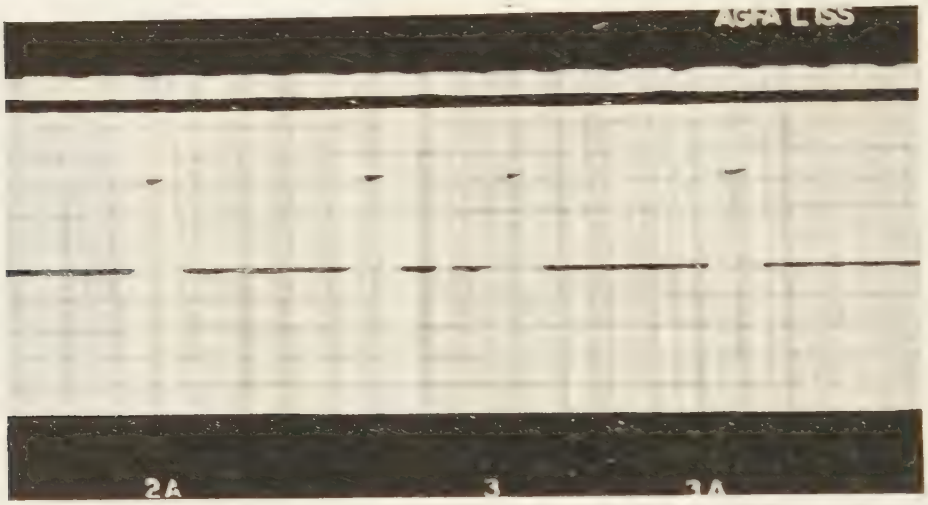


Fig. 12. — Reserve copy of the photographic record of a flawless fishplated joint, obtained by the masking method.

The apparatus requires no further accessories. It could if necessary be used to supplement any other equipment which does not of itself furnish all the information required.

Disadvantages.

Capacity of the apparatus.

a) Testing of fishplated joints only.

When the apparatus is used solely for the examination of fishplated joints in two lines of rails formed by sections of 30 metres length, it is possible to examine from 6 to 8 kilometres of track per working day of 8 hours, i.e. about 400 joints. The capacity

b) Testing of complete rails.

When the examination is extended over the whole length of the rail, the daily performance may amount to between 3.5 and 4.5 km of rail.

Personnel required (without lookout men).

Two men, workshop grades.

Acquisition cost.

The cost of acquiring and manufacturing the equipment amounts to 11 300 Dutch florins, equivalent to 12 490 DM. In assessing the cost of flaw detection, the depre-

ciation charge has been assumed to be spread over five years.

The opinions expressed concerning the range of applications, the sensitivity and the advantages of the apparatus do not call for comments. No shortcomings were found during the tests carried out with the ultrasonic testing apparatus of the German Federal Railways.

THE ULTRASONIC RAIL TESTING CAR.

1. Principles, objectives and results of the use of the testing car.

The speed of operating a hand-worked ultrasonic rail testing device is naturally rather low and the desire to be able to test rails at a high speed and over their whole

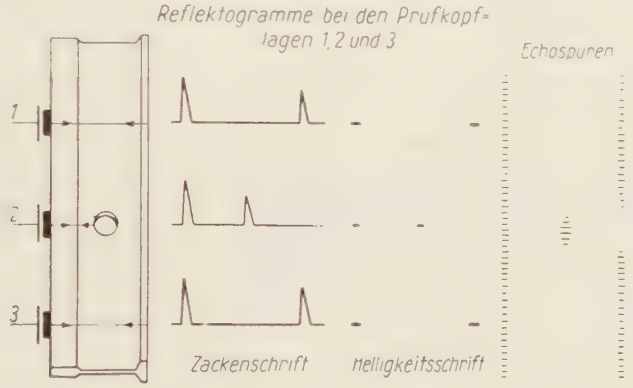


Fig. 13. — Oscillographs of a pierced rail, presented in the form of pulse records (« Zachenschrift », left) and brightness records (« Helligkeitschrift », right). On the extreme right are the echo traces (« Echospuren ») obtained when the recording strip moves at a speed proportional to that of the probe. The negative of the « brightness record » yields immediately the same result as the positive copy of a photographic record made in accordance with figs. 11 and 12.

Reflektogramme bei den Prüfkopflagen 1, 2 und 3 = oscillographs obtained at probe positions 1, 2 and 3.

The apparatus has meanwhile been perfected and has since worked completely satisfactorily, after a prototype had been tried out. The two rails are now examined simultaneously, and not only at the joints but over their whole length. The fluorescent screen need not be observed when no flaws are indicated. If a flaw is encountered, be it horizontal, oblique or transverse, a visible as well as an audible signal is received. In this case, the device is once more taken over the portion of rail concerned while the screen is observed in order to check the critical spot. One thus obtains a precise indication of the extent, position and character of the flaw. length is readily understandable. The solution of this problem was not easy but it has been successfully achieved.

The echo pulses arising from the flaws must be clearly indicated. It would have been conceivable to record all the successive oscillographs appearing on the screen as the unit moves along on the rail. To make sure that no flaw is missed, it would be necessary to take one photograph at least every 4 mm along the rail. At a testing speed of 8 m pr. second (29 km.p.h.), both the speed of the camera and the pulse repetition speed would thus have to be at least 2 000 cycles per second. The cost of such cinematographic recording would be

prohibitive, and its eventual interpretation would be difficult. One has therefore adopted a different method for the automatic recording of the pulse echos.

Consider the example of a rail which has a horizontal crack in the web as shown in figure 11 (top to bottom, left-hand side). If the rail is tested with a vertical probe from the running surface, one obtains the different curves (fig. 11, centre) corresponding to the three positions of the pulsator

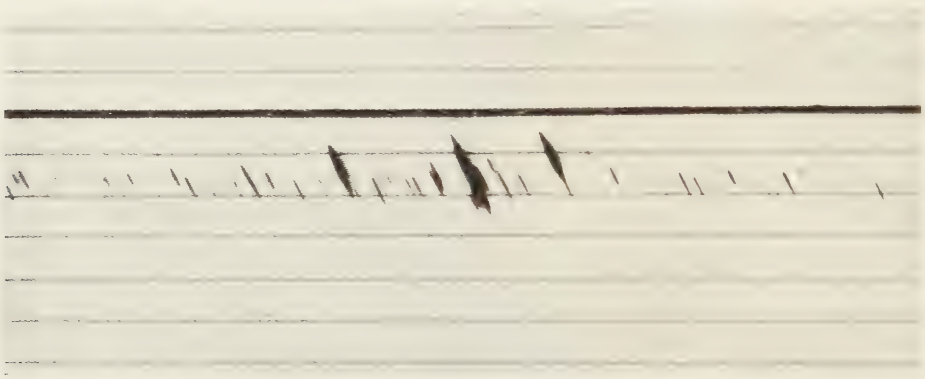


Fig. 14. — Record of transverse flaws due to flakes and kidney fractures in the foot of the rail.

on the running surface of the rail. Above the sound section of the rail, there appears, in addition to the transmission pulse, the bottom echo from the foot of the rail. Above the portion of the rail where the web flaw begins or ends, there appears a flaw echo as well as a bottom echo. Finally, over the cracked portion, the flaw echo alone remains. As the pulsator moves on, these curves appear successively on the screen of the oscillograph (fig. 11, top right). If the screen is now covered up with the exception of the reference line, the latter will show a discontinuity at all points where a vertical pulse appears (transmission pulse, flaw echo or bottom echo). These discontinuities are recorded on a film which travels in front of the oscillograph screen at a speed proportional to that of the pulsator, in the form of unexposed lines (fig. 11, right). On the left can be recognized the unexposed line due to the pulse transmission, and on the right that due to the bottom echo. A flaw echo such as, in this case, the one caused by the web flaw appears in the centre. The bottom echo (on the right) is arising where the crack extends right through the web. An oblique flaw whose echo, as explained earlier, is reflected to one side, is recognized from the fact that the bottom echo line on the film is interrupted over a distance corresponding to the projection of the flaw upon the bottom surface of the foot.

With the procedure just described, the whole of the film is exposed except for those places where the oscillograph records a pulse, i.e. a transmission pulse, a flaw echo, or a bottom echo. A recording thus obtained of a flawless fishplated joint is shown as a positive copy in figure 12. The four holes of the fish bolts are clearly recognizable, as are the interruptions of the bottom echo likewise produced at a rail joint.

It is also possible to suppress the reference line of the oscillograph completely and to introduce a spot of light merely at those points where a pulse is normally obtained. For this purpose, one applies to the Wehnelt cylinder of the cathode ray tube at one moment a sufficient negative voltage and, at the next moment, the posi-

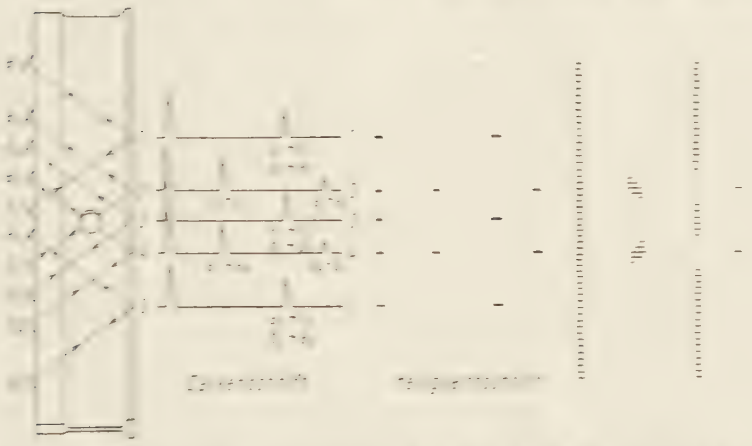


Fig. 11. — Diagrammatic representation of a portion rail as recorded by oscillographs of the pulse writing and brightness writing type and synchronised with timing.

Enregistrement à pulse record — Enregistrement à brightness record

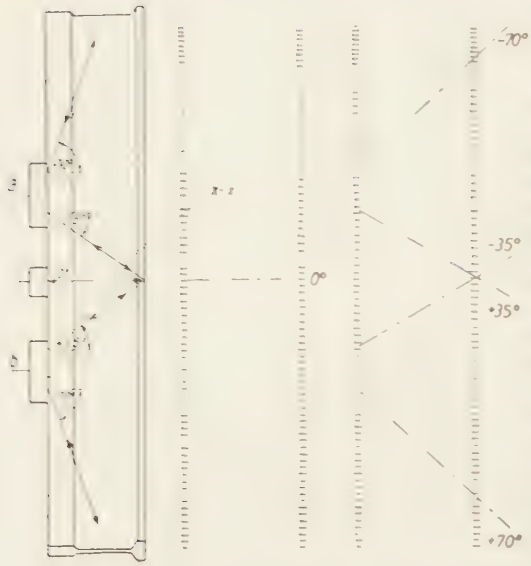


Fig. 16. — *Left :* Diagram of testing arrangement, showing the direction of the beams. *Centre and right :* Geometrical loci of echo traces of flaws lying in the same plane *x* - *x*.

which transmit or receive at + 35° and — 35°. They are placed at such a distance from each other that the ultrasonic beam of the one transmitter, when reflected from the bottom surface of the foot of the rail, is received by the other probe which then acts as receiver.

Figure 15 shows diagrammatically how an isolated hole in the rail is indicated on the screen and recorded on the film with the aid of this arrangement of oblique probes. On the extreme left are shown five symmetrical positions of the transmitter combination *a*, *b* on the length of rail containing the hole. In positions 1, 3 and 5, the bottom echo from the rail foot is encountered because the beam passes first from *a* to *b* and then from *b* to *a*. These echos are shown in the middle of the figure, with the pulse-writing record as well as with the record in luminous writing. In position 3, the beams pass around the hole whilst in positions 1 and 5, the hole is outside the range of the beams. When the set is in position 2, there are, in principle, two echoes. The first is a strong one caused by the wave train which travels from *b* to the hole and back to *b*. The second echo, which is weak and sometimes not even perceptible, is due to the wave train which travels from *a* to the bottom surface of the foot where it is reflected to the hole and returns to *a* in the same way. In position 4, the roles of probes *a* and *b* are reversed. The echo *a*—*a* precedes the echo *b*—*b*. The quasi-continuous record of the echoes of the rail with the hole, shown diagrammatically on the extreme right, should become clear when compared with the oscillographs. The angles of ± 35° were chosen because it was found from statistical investigations that this is the average angle between oblique flaws of this kind and the running surface of the rail.

When rail tests are being carried out, each rail is made to carry one pulsator with vertical transmitter, one with two transmitters of 35° converging as shown in figure 15, and one with two transmitters diverging at 70°. With the aid of two cathode ray tubes

Fig. 17. — Diagrammatic representation of a pierced rail as recorded by vertical probe and oblique ± 35° and ± 70° probes.

Fig. 16. — Horizontal crack originating at a flaw in the web

for each rail, the film shows respectively the echo traces of the vertical transmitter and the combined echo traces of the 35° and 70° transmitters so that there are for the two rails together four echo-tracing systems side by side.

Figure 16 shows the geometrical loci of the echo traces from flaws in the web plate of the rail. 1—4, for the two echo-tracing systems of one rail. The traces of echoes from flaws in the plane 1—4 are also recorded in the diagram for the vertical probe (0°) as shown by the system of lines to the right of the rail. The geometrical loci of the indications of flaws in rails given by the 35° and 70° probes are represented by the system of lines on the right-hand side of the figure. It will be readily understood that these geometrical loci must be oblique straight lines. Apart from a fixed amount, the distance between an oblique probe and the plane of the rail in which the defect is found, is proportional to the distance of the flaw from the running surface. The same applies to the distance

Fig. 17. — Oblique crack originating at a flaw in the web

(1) E. Martin and K. Werner: « Fehleraufzeichnung bei Überschall-Impuls-Laufzeit-Verfahren » [« Recording of flaws by a method based on the transit time of ultrasonic-pulses »]. « Archiv für Eisenhüttenwesen », 27, 1956, No. 9, pages 579-594.

Fig. 20 — Crack running vertically downwards from a hole in the web. The crack is detected by the cross of the two 35° probes

straight lines representing the « geometrical lock » is superimposed on the echo traces.

The recording of flaws is based on the echo indications of the vertical probe and the two oblique probes (35° and 70°). In this way it is possible to detect all the flaws by their echo directly, and not merely from the fact that the bottom echo is missing. Those flaws which are exactly perpendicular to the running surface cannot be detected directly by the vertical probe because the ultrasonic beam travels in the same direction as the flaw and cannot be reflected on its surface. All that may happen is that the generation of shear waves at the flaw may weaken the bottom echo. Similarly, oblique flaws such as fatigue cracks in the head of the rail cannot be detected with an oblique probing device if the direction of the crack is parallel to that of the ultrasonic beam. However, by using two oblique probes converging or diverging at the same angle of incidence, such a flaw can always be detected directly by one of the probes since, if one of the probes fails, the other will scan the flaw in the most favourable direction.

In figure 18 on top, the sketch of the rail shows a horizontal crack which has originated at a fish bolt hole. The flaw is recorded by the vertical probe also in the form of a horizontal line (centre). The gap in the bottom echo corresponds to the projection of the hole and the crack on the bottom of the foot of the rail. The crack is also indicated directly by the 35° probe in the form of a weak echo, and indirectly, because of the interaction of the two 35° probes, by a long interruption of the bottom echo

Fig. 21 — Fish-plated joint without defects.

Fig. 22 — Fish-plated joint with horizontal and oblique indirect flaw(s)

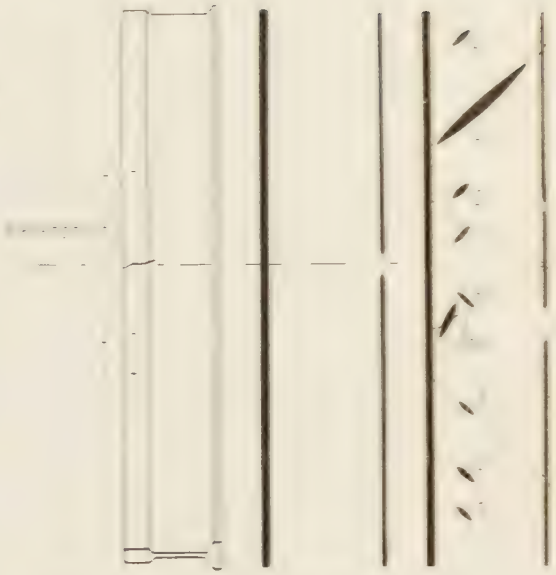


Fig. 23 — [illegible]

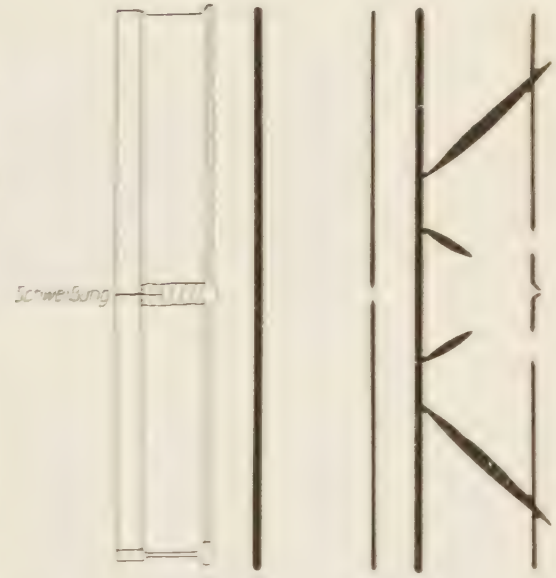
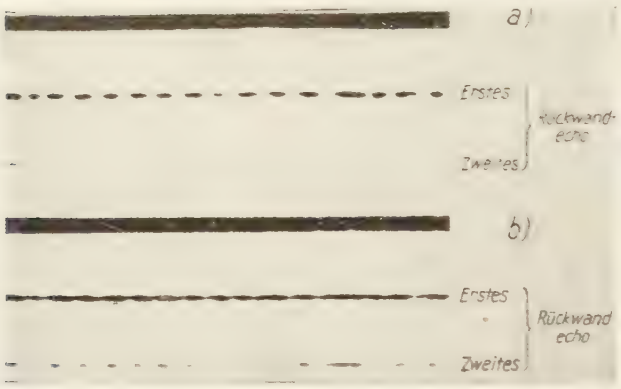


Fig. 24 — [illegible]

If the crack runs obliquely from the hole downwards (fig. 19), it will be directly recorded in the form of a very strong signal by the + 35° probe. If the crack extends all the way from the hole to the bottom (fig. 20) (a case which is extremely rare unless there are also other cracks present) then this crack, too, is detected by the [illegible] formed by the two 35° probes at the level of the bottom echo and at its location.

The recordings of certain single holes or of a succession of holes which often indicate the precise location of welds, compensation rails in curves, etc. are of special signific

and reflected at the vertical face of the gap. The ±70° probes record only three holes as one of them is always hidden by the gap. The surface of the gap is also indicated by the 70° probes. For the sake of clarity, however, these echo traces are not shown



— Bottom echo obtained from vertical scanning of corrugated rail :
— with small amplification;
with increased amplification.
Erstes Zweites Rückwandecho = first second bottom echo

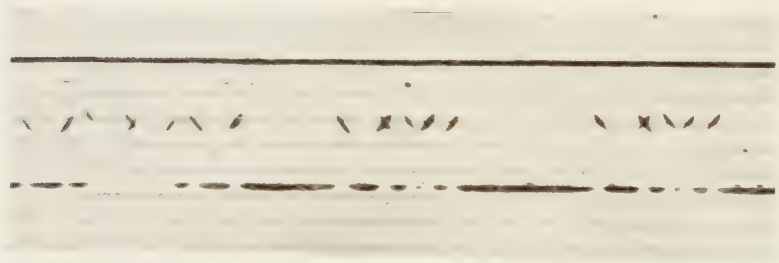


Fig. 26. — Records of holes and flaw-less fishplated joint in corrugated rail.

the oblique probes. A group of holes will indicate a fish-plated joint without cracks. But the picture becomes more complicated by the reflection of the waves from the gap between the rails. In figure 21, for instance, the oblique echo traces immediately to the right and to the left of the cross are caused by additional reflections of the waves coming from the —35° and +35° probes here: but their position can be reconstructed by reference to figure 16. Because of its constant repetition, the pattern of a flawless fish-plated joint is so familiar to the de-coding staff that the slightest deviation from this pattern will be noticed by them. Figure 22 shows a pattern of signals from horizontal and oblique bolt hole flaws. The horizontal flaws are mainly detected

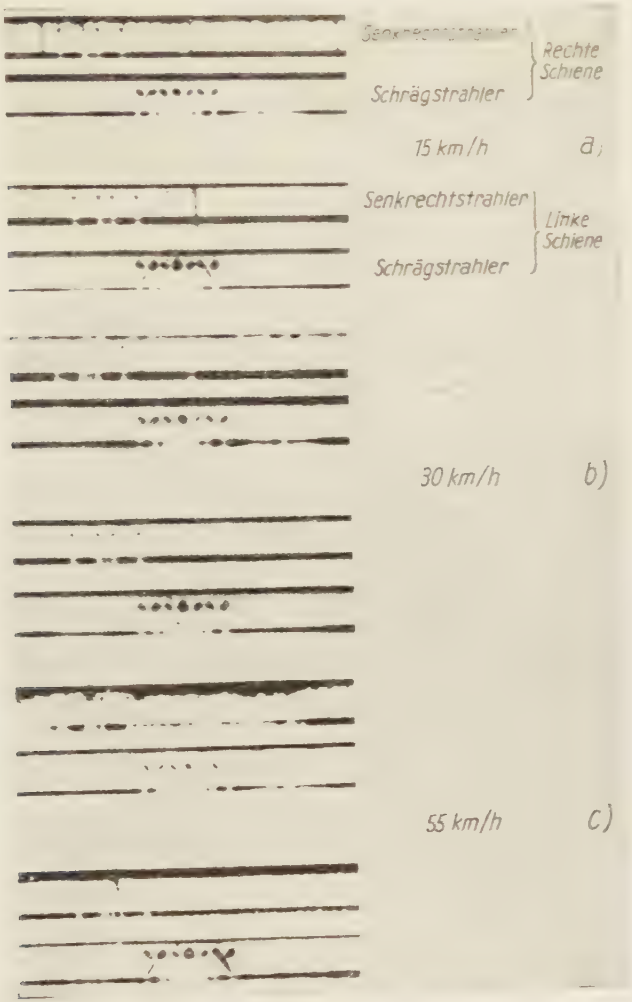


Fig. 27. — Records of the same flaw-less rail joints made at running speeds of 15, 30 and 55 km/h, respectively. Original length scale 1 in 100.

Senkrechtstrahler = vertical beam probe. — Schrägstrahler = oblique beam probe. — Rechte/linke Schiene = right/left rail.

by the vertical probe whilst the oblique flaws are, in this case, mainly recorded by the —35° probe.

Figure 23 illustrates the indication of transverse flaws in the head of the rail. Whilst the flakes, which are almost exactly vertical, are each characterized by two symmetrical echo traces, the smooth kidney-shaped flaw which originates at a flake and lies at an angle of 20° to the vertical axis of the rail, is mainly detected by the —70° probe. Nearly all the large kidney fractures

are also detected by the 35° probe of like sign, i.e. in the present case, by the +35° probe. At the recording point, the common bottom echo of the 35° probes is interrupted and, in the case of major kidney fractures the bottom echo of the vertical probe is also interrupted over a short distance. If the key diagram of figure 16 is moved over the echo traces, the correlation between the different echo traces and the flaws in the different planes will at once be clear. The diagram of figure 23 is drawn for the plane containing the kidney fracture. It underlines the endeavour to detect a flaw not from a single indication but by as great a number of echoes as possible. In this way, the detection of a flaw is ensured even if one or the other of the indications is missing, either because of an initially unfavourable position on the running surface, or because of imperfect coupling.

A defective rail weld is, for instance, characterized by the echo pattern shown in figure 24. In order to identify different types of weld defects, typical patterns have been drawn up. It is thus possible to distinguish a thermit weld from a flash butt weld by their different bottom echoes. Flaws in built-up welds and at points damaged by wheel slip also yield typical patterns.

The recordings are made on commercial-type perforated silver-bromide paper of the kind used for electrocardiograms. This paper has a width of 35 mm, corresponding to the width of a cine film. This paper was chosen firstly because photographic films of commercial types are more expensive, and secondly, because high-sensitivity films show too little contrast whilst high-contrast films are not sufficiently sensitive. For instance, a low-contrast film will not show with sufficient clarity the brief interruption of the bottom echo due to a hole in the rail because the gap is covered by the print of the remanence of the picture on the fluorescent screen.

The ration between the length of track covered and the length of the paper tape passing before the cathodic oscillograph can be adjusted at will to 1 in 50, 1 in 75, or 1 in 100. It is thus possible to record, for instance, 100 m of track on 1 m of paper. The recording paper is driven by one of the axles of the vehicle. As a means of locating the flaws, special markers are recorded every metre and every five metres. The marker pulse transmitter is controlled by a shutter disc mounted on the camera drive, by a lamp and a photo-electric cell so that the use of any mechanical contact transmitter has been avoided. In order to locate a rail flaw, the so-called kilometre stones spaced at 100 m intervals are photographically recorded on the paper strip.

Fig. 28. — Kidney fracture:
(*a*) as recorded on the strip;
(*b*) as seen when rail was removed and broken open.

For this purpose, the number of the first stone is recorded in the camera with the aid of a four-digit counter and reproduced on the recording strip at the moment when the recording point at the head of the coach passes the stone concerned and an electronic flash lamp placed in the camera behind the counter is actuated. As the recording point is situated about 5 m, or in the other direction of running, about 18 m in advance of the ultrasonic tester, the indications of the kilometre stones are always recorded prematurely if they are recorded directly. This error can be corrected during de-coding but it is a tedious job for the de-coding staff. One has therefore designed an electronic displacement recorder, fitted with decatron valves which have the effect of delaying the operation of the electronic flash lamp by the time required to cover a distance equal to that which separates the recording point from the probe concerned. The control pulses required to actuate the time lag device are supplied by the shutter disc referred to above.

Experience has shown that at testing speeds of about 20 km pr. hour, the position of the kilometre stone can be recorded to within half a metre. With such a reference mark on the recording strip, it is perfectly feasible to re-locate a defective rail joint. By reference to the nearest rail joint, any flaw in the middle of the rail can then be located with an accuracy of at least 10 cm. As already explained, it is also possible to use, as reference mark, any holes that are visible from outside. Moreover, the position of the flaws can be related to that of the sleepers as these are distinguished by a different bottom echo when the rails has been in the track for some time.

Fig. 29. — General view of rail test car, using the body of a standard two-engined rail bus.

The sound waves are introduced by probe heads which are moved along the running surface. The oscillating units are housed in longish skid-shaped slides mounted in gimbals. This arrangement, which had been successfully tried out with the USPG ultrasonic testing apparatus, has been perfected so as to allow high speeds. In the oblique probes, the actual oscillating units are protected by the wedge which precedes them. In the vertical probes, they are likewise protected by specially inserted pieces which,

to judge by present experience, must be good absorbers of ultrasound in order to suppress the unwanted multiple echoes originating in these parts themselves. In the USPG assembly the body of equipment

The wear of the probe heads is largely governed by that of the steel skids forming the frame in which the vibrating units are housed. For the gaseous coupling, water is used, which flows across the skids. As long

Fig. 30. — Interior of railcar, seen from front driving cab. On the right, the sound and heat insulated casing of the generator. On the left, cupboard, refrigerator and cooker. Removable parts of flooring allow access to engines.

chloride are used for this purpose. On the rail testing coach, a polyamide or hard rubber is used.

E. Martin and K. Werner, paper read at a joint symposium held by the « Deutsche Gesellschaft für Metallkunde », the « Société Française de Métallurgie » and the « Verein Deutscher Eisenhüttenleute » « Prüfung metallischer Werkstoffe » (« Testing of metallic materials »), Saarbrücken, 27th and 28th March 1953. — German patent DBP 934 504.

as the running surface is uniform, in the direction of the rail axis, the coupling remains uniformly good. If the rails show corrugations, the quality of the coupling varies with the alternation of the crests and low spots of the corrugations, being better over the former than over the latter (fig. 25 top). However, the quality never becomes so poor that it is not possible, by increasing the amplification, to restore the interrupted bottom echo (fig. 25 bottom). The poorer

Fig. 11. — Interior of trailer with accommodation for staff and four testing cars.

2. The rail testing car and its equipment.

The testing equipment has been mounted on a small standard two-bogied trailer with vestibules, type VT 50 VM (fig. 10). Its maximum speed is 80 km/h. The lower speeds required for the test runs (ranging from 10 km/h upwards, but not exceeding the very limited length of line). The rail car itself contains, in addition to the

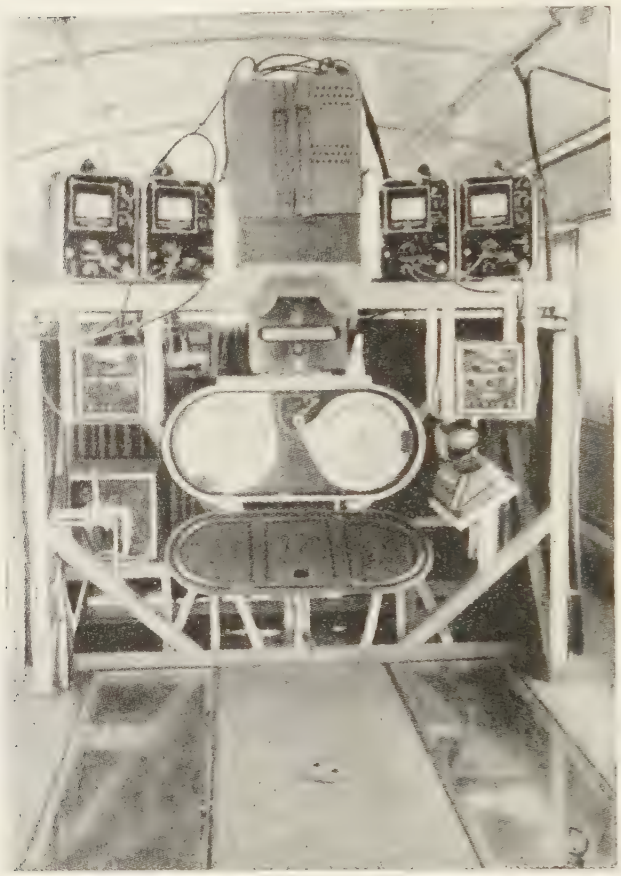


Fig. 32. — Railcar trailer with testing equipment. The lid of the film cassette is opened. On top are two ultrasonic detectors on either side: in the centre are the cathode ray tubes and, below them, the film camera. The eye piece above the film cassette permits the verification of the correct position of the luminous spots required for the « brightness record ». Removable plexiglass panels in the floor permit the observation of test bogie and probes and afford access to them from the interior of the car. The arrangement of the apparatus on the left and right hand sides in the car corresponds to that of the probe heads with which they are connected. The outermost detectors are connected with the oblique probes, the innermost with the vertical probes.

engines which are housed in the underframe, the generator supplying current for the testing apparatus which is placed in the car body, and the quarters for the staff (fig. 30 and 31). A telephone installation ensures intercommunication between the driving cabs and the trailer when the tests are in progress.

As the testing apparatus is mounted in the trailer (fig. 32), it is protected against vibration caused by the engines. The installation comprises four ultrasonic devices (8) of commercial type, four brilliant piece for the observation of the correct position of the luminous spots for the « luminous » writing. Their requisite normal position corresponds to the path of the test skids on the running surface directly

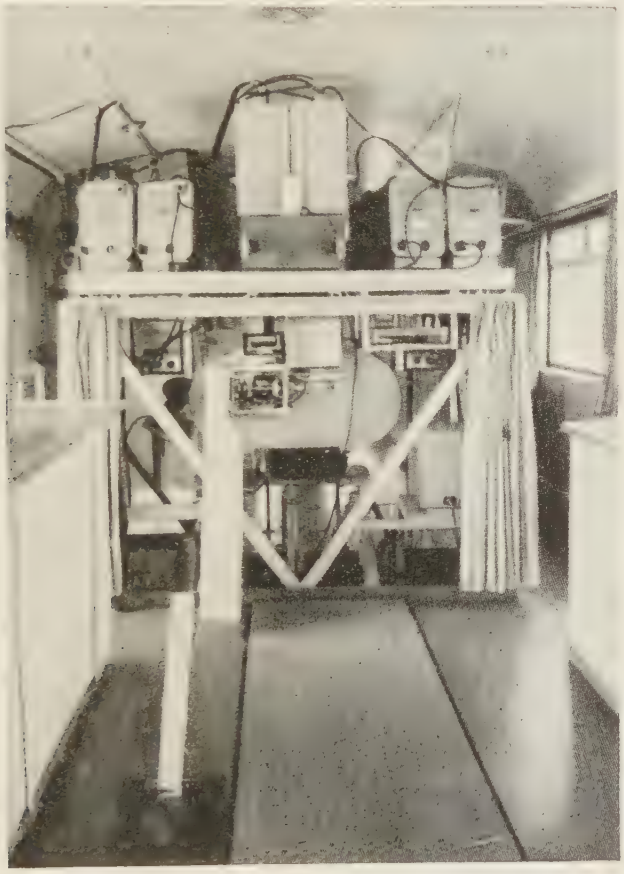


Fig. 33. — Rear view of testing equipment with camera drive. On the left is the water tank.

cathode ray tubes with little remanence and the camera. Above the film cassette (seen open in the photograph) there is an eye-

above the web, and can be obtained in a completely satisfactory way by transverse adjustment of the skids by means of remote control from the test compartment. Two control devices placed below the ultrasonic detectors produce warning signals when the bottom echoes of the vertical probes have been missing for a given time.

(8) The ultrasonic testing devices, including those mounted in the railcar, were supplied by Messrs. J. and H. Krautkrämer, Cologne-Klettenberg.

Fig. 35. — Test bogie lifted.

Beyond the [illegible] installation (fig. 33) are the camera drive and the electronic transmitter for the distance markers. The observer who sits next to the railcar driver and records the kilometre stones, is also able to mark on the recording strip, by means of code numbers, certain features such as rail corrugations, type of sleepers,

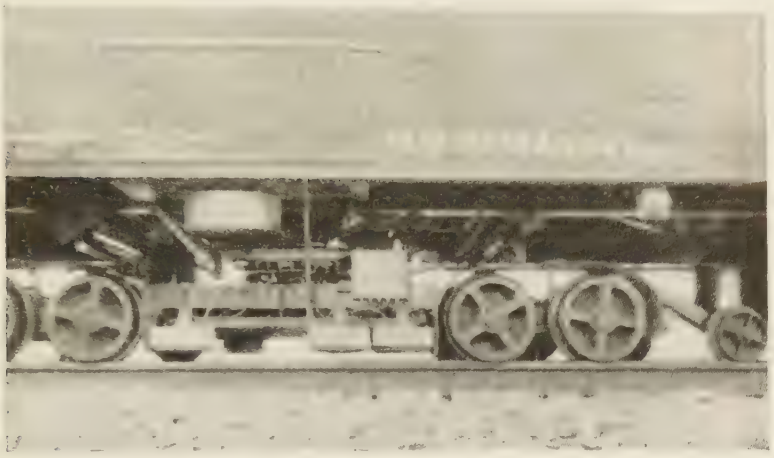


Fig. 36. — Test bogie with lifted probe assembly.

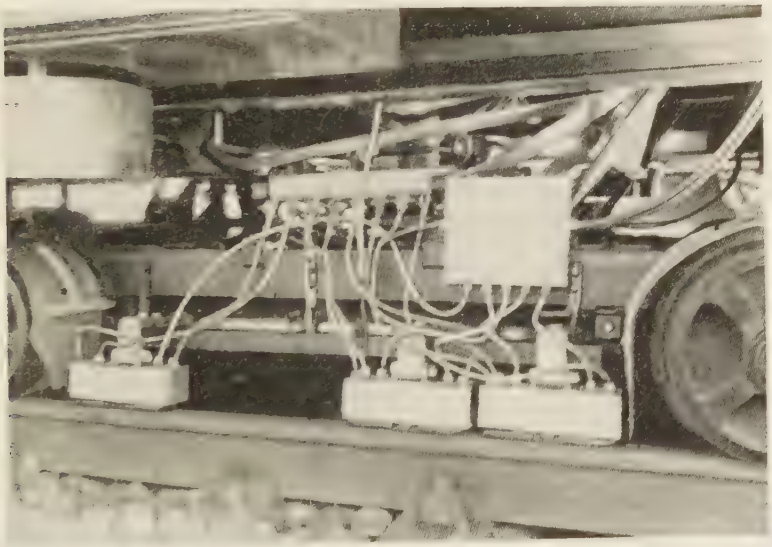


Fig. 37. — Arrangement of probe heads. The head on the right contains the + 70° and — 35° probes, the one in the centre the + 35° and — 70° probes, and the isolated head on the left the vertical probe

stretches of continuous track, home signals, etc. These indications are of assistance when the record is interpreted.

Apart from the testing apparatus, the trailer contains a darkroom where the test strips can be developed, as well as a tank containing the coupling liquid. Recent tests have shown that the water consump-

Fig. 38. — De-coding equipment at the Materials Testing Bureau.

Fig. 39. — Room where the recording strips are developed.

tion, hitherto amounting to 4 cubic metres per 100 km, can still be appreciably reduced. The wear of the probes, i.e. that of the plates or wedges is considerably lower than was anticipated, and amounts to about 0.6 mm per 1 000 km of track. With the tests carried out so far, extending over nearly 2 000 km, it was found that certain probe heads did not require renewal. The only case where higher wear may be expected is that of track where the rails have recently been ground in order to remove surface corrugation.

Figure 34 shows the test bogie beneath the car, with the probe heads in their working position between the guide wheels. The bogie is fitted with idler rollers whose flanges bear against the inner face of the rail, and is so designed that it cannot be derailed. The entire bogie can be lifted (fig. 35) when the vehicle proceeds to or from the testing site without actually car-

rying out tests. It is also possible to lift the probe heads only while the bogie remains on the rails (fig. 36). Figure 37 shows clearly the probe heads of one rail with their electrical and water connections, and the actual arrangement which differs to some extent from the diagrammatic arrangement shown in figure 16.

3. Interpretation of the recording strips.

The recording strips are not developed and interpreted in the car but at the laboratory of the Materials Testing Bureau of the Central Research Office of the German Federal Railways at Minden. With the de-coding apparatus (fig. 38), it is possible to examine films in transmitted light as well as to examine photographic paper strip under incident light. The 35 mm paper strips hitherto used for the recording are enlarged about five times to facilitate interpretation. Figure 39 is a view of the room in which the records are developed and fig. 40 shows the room where the strips are dried.

The results of the interpretation are recorded in reports which describe the position and type of the rail flaws detected, using the classification shown in figure 10. These reports are sent to the Regions of the German Federal Railways and enable them to take all necessary action. Rail defects belonging to Group 1 are reported by telephone to the regional authorities immediately upon discovery.

THE FUTURE.

The value of rail testing by means of ultrasonics lies not only in the greater margin of safety afforded by the timely detection of rail defects, or in the possibility of adhering to a replacement programme causing a minimum dislocation of traffic. This method of examination affords such a comprehensive picture of the condition of the rails that maintenance and reconditioning work can be carried out much more methodically than in the past. This is because the ultrasonic test also serves to provide information about rail corrosion and about the extent to which the foot of the rail has become lodged in the supporting plate. On welded track, the ultrasonic survey permits conclusions regarding the quality of the rail weld or rather, the quality of the work performed by the welding teams.

Ultrasonic testing will no doubt play an important part in the planned, and therefore economically more efficient, maintenance of railway track.

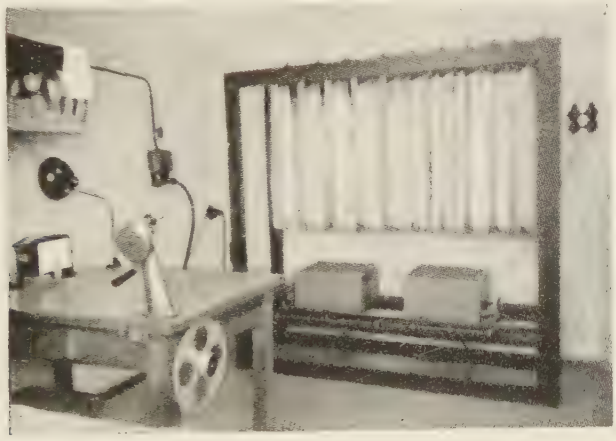


Fig. 40. — Room where the recording strips are dried.

[625 .28]

The most economical method of traction,

by Dipl.-Ing. Richard WOSCHNI,

Professor at the Dresden Higher Transportation School.

Lecture read to the 2nd Scientific Transport Congress, held at Dresden on the 15th June 1956.

(*Deutsche Eisenbahntechnik*, No. 10, October 1956.)

1. Introduction.

The importance of transport for the trade of a country increases as industrialization develops. Although this latter has been somewhat retarded, or more accurately developed on unilateral lines owing to the two world wars, its progress during the XXth Century has followed a rhythm which even the perspicacity and optimism of a *List* or *Goethe* could hardly have foreseen.

The development of transport, which suffered a great deal of material loss, especially during the world war, has remained a long way behind that of world trade, so that there is a risk that the transport undertakings will no longer be able to meet the economic system requirements adequately. This risk is particularly great in those countries where industrialism has gone forward at a giant's pace, such as in the Soviet Republic and Peoples Democraties. This is why the question of transport has become of political importance. It is therefore understandable why during the XXth Congress of the Communist Party of the Soviet Union, eminent politicians and statesmen made statements on the objectives of the future evolution of transport and why the Governments of the different countries are striving still harder to guide this evolution in the desired direction by legal measures.

This is becoming more and more the case in the territory of the East German Democratic Republic. That is why, here again, the 25th Plenary Session of the Central Committee of the Unified Socialist Party of Germany demanded, in June 1955, that the most modern technique should be applied in the field of transport as elsewhere. As a result the heads of the Administration in the different ministries were obliged to obtain a faithful image of the economic value of the different methods of traction, with the assistance of the newly set up technico-scientific Consultative Councils.

In Western Germany also, great importance has been attached to the solution of this problem which has never been settled so far, and it has been dealt with by a Study Commission known as the « Dieselschienenverkehr » (Diesel railway traffic Commission) consisting of a large number of experts in transport and constructional matters. The report of this Commission, the fruit of four years work, has been published in the form of a book called : *Diesel vehicles in railway traffic* (1); it is undoubtedly a perfect example of an attempt to make an economic comparison of the three methods of transport : steam, Diesel and electricity, on an unassailable basis.

I have given myself the job of studying the economy of the three methods of transport from a different angle. I want to begin the study of the problem by trying first of all to determine the conditions a system of traction must fulfil as far as the transporter and trade are concerned, and then reporting how the different systems are able to meet these conditions.

The conditions which the « railway » transport operator has to lay down for the different methods of traction are : 1) of a

(1) « Dieselfahrzeuge im Schienenverkehr », published by Carl Röhrig-Verlag, Darmstadt and Cologne, 1954.

technical and operating nature, and 2) of an economic nature. The operating conditions may be characterised by the following notions :

1. Reliability of operation and working.
2. Simple and adequate design.
3. Simplicity of driving and control.
4. Polyvalent use.
5. Wide radius of action.
6. High speed.
7. Great acceleration on starting.
8. Sufficient reserve of power and overload capacity.
9. High specific powers (HP/t).
10. Installation of considerable specific powers (HP/m^2 or HP/m^3) or which do not take up much room (m^2/HP or m^3/HP).
11. High weight per HP.
12. Simple division and distribution of the tractive effort.
13. Constant tractive effort.
14. Considerable specific mileages.
15. Constant availability.
16. Able to run in either direction.
17. Simple and certain coupling up or concentration of the source of power of the motor or of the driving machinery.
18. Stability of running of the vehicle.
19. Little stress on the permanent way.
20. Simplicity of servicing, maintenance and overhaul.
21. Cleanliness in operation.

The economic conditions can be summed up in a single sentence : low direct running costs.

Now, how do the three systems of traction show up as regards the realisation of these conditions ?

2. Technical and operating conditions of an optimum traction system.

2.01. Reliability of operation and working.

During the 120 years in which it has been used, steam traction has given proof of its perfect security of operation and working; it is the same with electric traction which, though in use for only about half as long, has developed at a very fast rhythm, from both the constructional and operating points of view. From the point of view of reliability of operation, these two methods of traction could hardly be improved upon. Even the introduction of new systems of electric traction could hardly increase the degree of reliability of operating to any appreciable extent. The Diesel engine made its debut on the Reichsbahn as a locotractor shunting engine and a railcar engine about 1930, and has developed as shown in figure 1. The evolution of the stock of locotractors shows to some

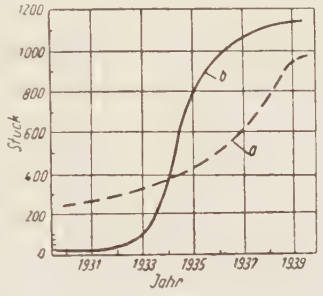


Fig. 1. — Stock of railcars with internal combustion engines and loco-tractors of the Reichsbahn.

a = railcars; *b* = loco-tractors.

extent the haste with which the Reichsbahn then adopted this completely new method of traction, and the curve of the numbers of Diesel railcars, the constant increase in introducing Diesel engines on railway vehicles.

If this development of its use on the Deutsche Reichsbahn is already a proof to some extent of its reliability of operation on the railway for these two types of service under German conditions, the Diesel engine has proved in the country in which it originated its great reliability of operation on the roads, as well as in ships and aircrafts; the Junkers, Maybach, MAN, Deutz, etc. engines have become world famous. If the fastest development has

been in the United States, on the basis we created, this is a consequence of two world wars.

Since then, the driving of railway vehicles by Diesel, the locomotive in the United States and the railcar in Germany, have proved that from the point of view of reliability of operation, they are in no way inferior to the other two methods of traction. This fact has already been expressly stated in September 1950 by the International Railway Congress at Rome.

2.02. Simple and adequate design.

As far as this condition is concerned, it must be considered that in order to do its work, the steam locomotive requires a boiler and steam engine with its valve gear, which are not particularly simple constructional details. The old type Stephenson steam boiler, at any rate, must be considered as outmoded in the present state of the technique. Unfortunately, the trials carried out with the object of replacing the Stephenson boiler by a modern tubular boiler, of the *La Mont* type, were not satisfactory.

The mechanism of the steam locomotive, with the classic rod type of drive, was undoubtedly a simple type of construction, but cannot be considered adequate today. The primitive and anti-economic character of the method of lubricating the rods, the difficulties encountered in maintaining the axle spacings, must be considered out of date after 120 years and as incapable of improvement. That is why, abroad, efforts are made periodically to perfect a steam turbine drive, which gives uniform couple, even if the advantage of being able to utilize part of the difference in pressure at the lower values has to be renounced. An astonishing fact is that in the development of the electric locomotive, individual axle drive was only thought of after rod drive had first of all been used.

A new and modern design was adopted when using Diesel engines on railway vehicles : the interposition of the transmission which had given such good results on road vehicles, to connect the Diesel engine to the driving axle. As on road vehicles, an elegant solution was found at once when German designers with their attention to detail put out the well known hydraulic drives : VOITH, Krupp-Lysholm, Maybach, AEG-EMG, etc., components which function reliably and operate with little loss of power yet are able to transit high powers.

The adoption of such a drive on railway vehicles was bound to have considerable economic repercussions, when it is remembered that the consumption of fuel on the road and on the railway is in the proportion of 100 : 25, especially on account of the smaller losses with which a steel tyre rolls on a steel rail compared with the rolling of a pneumatic tyre on the road, often at varying pressure.

The constitution of the Diesel with all its improvements, such as supercharging, high supercharging with air cooling, are not complicated according to modern ideas. It is therefore not possible to state that one or other of the three methods of traction considered is superior from the point of view of simplicity of constructional detail.

2.03. Simplicity of drive and control.

It is not possible to pretend that the driving and control of a steam locomotive is simple. The duties of the engine crew, in this case the driver and fireman, are so many and numerous that the work has had to be divided. On the skill of the fireman depends the output of the boiler. The physical and intellectual effort required of the crew are very great. As the management of the « power supply » depends to some extent on the two hands of the fireman, the risk of burning the fire box or of water hammer if the superheat falls are two nightmares of the engine crew; the man and his responsibility are of prime importance.

The physical effort required of the fireman for 120 years should now belong to the past; mechanical firing at least must be introduced. But even in this case, the work of the engine crew remains very complicated and necessitates a driver and a fireman.

With the electric locomotive, the power is taken from the catenary. No physical effort is required of the driver. Observation of the gauges is simple and does not interfer with his observation of the line. The position is much the same on a Diesel locomotive where up to date servo-control requires very little effort to operate the controls.

2.04. Polyvalent use.

With steam traction, it soon became necessary to make a distinction between the different types of service : express trains, stopping trains, freight trains, shunting, and to use different types of locomotives for each, characterised by their special types of construction. These different types have conditioned all the previous period of evolution as far as the design of the steam locomotive is concerned. The study of the engine was typically based on its method of use, thereby leading to such widely different forms of construction that the use of such locomotives for different types of service gave rise to various difficulties only too well known to all operators.

The development of electric traction resulted in arrangements which made it possible to make a considerable reduction in the number of types. The idea of abandoning the single purpose locomotive for one that could be used for several purposes, and therefore more widely used, found powerful support in the advantages of electrical transmission, and for a certain time it was thought that the operating department would be very pleased to have locomotives which could haul express trains as well as freight trains. But the different behaviour of the motors at high or low speeds of rotation, as we shall see further on, was a serious obstacle to the construction of locomotives that could be used for all purposes. Conditions are similar for Diesel locomotives; however with these latter two types of traction the subdivision of types of locomotives as a function of the different services need not be carried so far so that the possibility of using electric and Diesel locomotives are definitely wider than those of steam locomotives.

2.05. Wide radius of action.

The specific consumption of power and fuel supplies carried determine the maximum mileages, i.e. the radius of action of steam and Diesel engines. As the steam locomotive uses about seven times as much water as coal, and the capacity of the water tank on the tender is limited, it is necessary to allow for filling up with water several times before it is necessary to refuel with coal. In the case of the electric locomotive, the radius of action is determined by the length of line fitted with the catenary; apart from this, availability of power and the radius of action have no limits.

The comparison made by Mölbert in the book already quoted : *Dieselfahrzeuge im Schienenverkehr*, for a certain volume of requirements in fast services under characteristic conditions obtaining on the German lines, shows the specific consumption figures as 25.2 t of coal per million gross t/km (including the locomotive) with steam traction, and 3.47 t of Diesel fuel per million gross t/km with Diesel traction. When fully stocked up, i.e. with 10 t coal in the case of the 01 and 2.58 t of fuel oil in the case of the V 200, a maximum mileage of 780 km with steam traction and 1 800 km with Diesel traction will be obtained. The proportion of the radii of action is therefore 1 : 2.3. But account must also be taken of the fact that the steam locomotive must also replenish its water supply twice.

The radius of action of a motor vehicle can also be greatly limited by external causes. Bottlenecks and traffic disturbances, which all railways remember suffering from during the war, are still possible today owing to the insufficient capacity of certain lines, and often lead to unexpected and prolonged stops of trains at signals, etc., involving locomotive and staff in much and intolerable waste of time. The pretended shortage of locomotives, which the operating department then blames, is hard for the traction department to bear since it is quite unjustified. In cases of this kind, steam traction is greatly handicapped compared with electric traction or Diesels, because coal and water continue to be used to a

certain extent, so that the radius of action is still further limited.

2.06. High speed.

Modern railway traffic in general involves high speeds in order to reduce transport times for passengers and goods, and allow of more frequent services on heavily loaded lines. The development of fast railcar services and the increase in the speed of freight trains before the last war are characteristics of the trend of modern, fast railway traffic. In this field, the three systems of traction have met all the conditions imposed on them to date.

The streamlined BR 05 steam locomotive, specially designed by the Deutsche Reichsbahn in the thirties for fast traffic, which held the world speed record for steam locomotives with 195.6 km/h reached during trials carried out in the summer of 1935 between Hambourg and Berlin, show that the classic type of rod drive can still be used, though with 2 300 mm driving wheels, it is true. It appears that this is about the top speed possible with rod drive, because from the constructional point of view it is no longer possible to make the driving wheels any larger because of starting, and because if this cannot be done, the speeds of rotation and the piston speeds become excessive.

The 2.D.2 streamlined express of the Norfolk & Western R.R. in the United States, one of the few American Companies which have remained faithful to steam, at 160 km/h has to have an average piston speed of 12.95 m/sec. As far as the traction of trains by Stephenson type locomotives is concerned, it is therefore not possible to count upon any great increase in the speed above 200 km/h.

Electric traction of railway vehicles has already shown how suitable this method is for high speeds, since during trials carried out in 1903 on the Kichterfeld-Zossen line, a speed of 210 km/h was reached. After a new increase of the maximum speed to 243 km/h, trials carried out by the S.N.C.F. last year with two electric locomotives with modified gears, resulted in the well known record speed of 331 km/h, which shows that electric traction, both from the point of view of the gearing-down of engines and the picking up of power by the pantograph, is perfectly suitable for the highest speeds.

Diesel drive with electric transmission through a generator and engine has passed its tests even at the highest speeds on the Deutsche Reichsbahn (fast railcars) and in the United States (locomotives). The hydraulic drive can also be considered as fully tested, from the economic point of view as well, on the Reichsbahn at any rate, as regards high speeds in the case of railcars.

A modern method of traction must however work regularly and economically even at reduced speeds (climbing gradients and in shunting). Whereas the steam locomotive with its well known elasticity is able to give a considerable tractive effort certainly and constantly even at very low speeds, it is not quite the same with its two competitors. The electric locomotive is somewhat more restricted from this point of view. It can only be used economically above about 30 %, or at least 25 % of the maximum speed, because of the well known difficulty of getting rid of the heat produced. With Diesel traction with hydraulic drive, the Diesel can work continuously up to 15 % of the maximum speed, which is manifestly a decisive advantage as regards the possibility of using Diesel locomotives for multiple purposes (shunting services).

For example on the two German Diesel locomotives with hydraulic drive, the 1 000 HP V 80 and the 2 000 HP V 200, the working power is retained to 16 and 14 % respectively of the maximum speed, whereas with the electric drive, for example on the new VL 2045 Diesel locomotive of the Austrian Federal Railways, of 1 000 HP, and the most recent Diesel locomotive of the S.N.C.F., the 060 DE of 2 000 HP the limit of the working power is reached at 37 % and 29 % respectively of the maximum speed.

According to DORRER (10), fulfilling the condition of using as high speeds as possible in order to reduce transport times, has led in the United States to reduction in transport time quite unknown before since

the Diesel locomotives were put into service. For example, the streamlined New York-Los Angeles train covers the 5 100 km run in 60 hours at an average speed of 85 km/h. The Chicago-Los Angeles run is now made without change of engine at an average speed of 93 km/h, and only takes 39.6 hours compared with 72 hours by steam traction.

SCHAEFER (9) stresses the advantage of the long runs made by the American Diesel locomotives by quoting the following mileages :

in passenger service, on the Chicago-Los Angeles line, 3 600 km with 14 changes of crew, and on the Chicago-Las Juntas line, 1 700 km with five changes of crew; in freight service, on the Kansas City-Belen line, 1 430 km with eight changes of crew.

2.07. Great acceleration on starting.

To increase the number of services on the railway, higher starting speeds are required. A typical example is that of the constant evolution of the Berlin Metro. With steam traction, with the T 12 locomotive with its very large cylinders, accelerations of 0.1 to 0.3 m/s² were obtained when starting up at more or less the limit of adhesion. Today, owing to the distribution of the power between the driving axles, on the metro accelerations of 0.7 to 1 m/s² are obtained, i.e. at practically the limit of physical comfort.

Owing to the importance of the degree of variation of tangential stresses which is $\delta = \frac{Zi_{max}}{Zi_{avg.}} = 1.09$ in the case of the six coupled locomotive with simple expansion, more than 1.22 for the four coupled locomotive with simple expansion and up to 1.5 for the compound six coupled locomotive, with the rod drive of the steam locomotive it is not possible to use the adhesion due to the friction between the wheel and the rail to the same extent as on electric or Diesel locomotives. On the average, it is only possible to count on 80 % of the adhesion in the case of the electric or Diesel locomotives. In the same way, the rod drive of the steam locomotive is at a disadvantage from the point of view of the utilisation of the adhesion owing to the periodic variations in the axle loadings under the action of the reciprocating masses and the revolving masses leading to unbalance.

In figures 2 and 3, the effort/speed and power diagrams are shown for a high speed locomotive of each of the three systems of traction, capable of developing 2 000 HP at the tread. The superiority of the Diesel locomotive on starting can be clearly seen. The characteristics are based on the adhesive weight of 78 t for the Diesel locomotive, 60 t for the steam locomotive and 64 t for the electric locomotive.

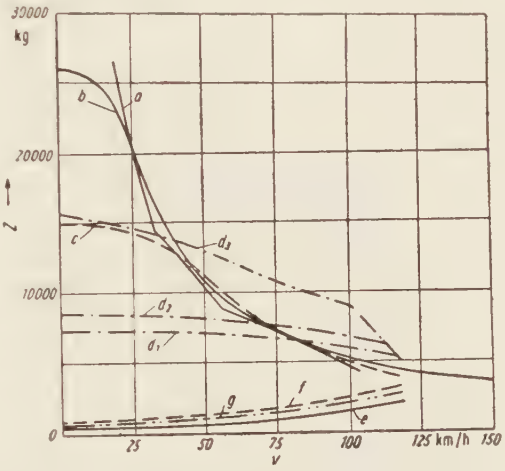


Fig. 2. — Comparison of the characteristics of the tractive effort in express train service.

a = hyperbola tractive effort - speed for 2 000 HP;
b = Diesel locomotive G_R = 78 t. μ = 0.33;
c = steam locomotive C_R = 60 t. μ = 0.25;
d_1, d_2, d_3 = electric locomotive G_R =64 t;
d_1 = continuous tractive effort;
d_2 = tractive effort at hourly rating;
d_3 = tractive effort during overload.
e = resistance to forward movement of 10 express coaches (400 t) on a straight, level line;
f = total resistance, steam locomotive included;
g = total resistance, Diesel or electric locomotive included.

We must deal here briefly in principle with the characteristics used for comparison between the two graphs, which apply to high speed locomotives and involve a boiler power of 2 240 HP in the case of the steam

locomotive, 2 000 HP at the tread in the case of the electric locomotive and an engine power of 2 500 HP in the case of the Diesel locomotive. Unlike the electric locomotive, which has a driving engine with a more or less uniform couple, the steam locomotive and Diesel locomotive are engines of approximately the same power, calculated from the speed allowed by the adhesion.

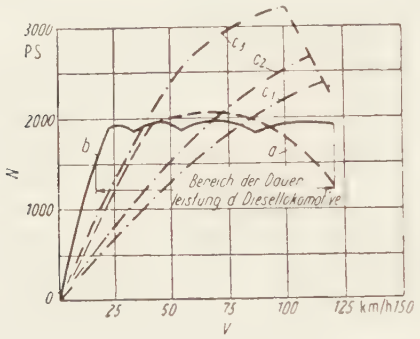


Fig. 3. — Comparison of power characteristics in express train service.

a = steam locomotive;
b = Diesel locomotive;
c_1, c_2, c_3 = electric locomotive;
c_1 = continuous power;
c_2 = power at hourly rating;
c_3 = overload power.

In the case of the steam locomotive, the peak of the power curve is reached at the optimum speed, because this gives the most favourable specific consumption of steam. Below the optimum speed, right down to the speed of adhesion, the power of the steam locomotive decreases owing to the losses due to insufficient expansion which increase with the degree of admission; in the same way the power also falls off, generally more rapidly, above the optimum speed, owing to the increasing losses due to wiredrawing.

The form of the curve of the power characteristics of the Diesel locomotive is determined by the degree of multiplication obtained at the different transmission ratios, and the greater or smaller decrease in the speed of rotation; it consists to some extent of separate characteristics for the different scales of speed. It shows that on the whole the power is more constant than on a steam locomotive. In particular, the Diesel locomotive keeps its power at high speeds, whereas with the steam locomotive this falls off considerably. Above all, however, they show the superiority of the Diesel locomotive right down to the minimum speed without risk of wheel slip, which is extremely rare on this engine (15 km/h) and allows the whole power of the engine to be used. The form of the curve of the characteristics of the Diesel locomotive makes it the ideal universal engine, guaranteeing the use of its full power in low speed shunting services as well as stopping passenger services with their frequent starts, and without any appreciable drop in power at high speeds. As far as the electric locomotive is concerned, during its evolution to its present stage which may be said to be without exaggeration more or less perfect, and which has been extraordinary fast the importance of the parameter « heating » was recognised immediately, and right from the beginning, three degrees have been taken into consideration in the power characteristics : the continuous power, the power at one hour rating, and the short duration overload power. For this reason, there are three curves for the power characteristics, corresponding to the three degrees of power. The following chapter shows that a similar grading of the power ought to be considered for steam locomotives, though based on other parameters.

The curve characteristics of the electric locomotive clearly show its inferiority at low speeds compared with the Diesel locomotive, even when the overload power is used. At 20 km/h in fact, the tractive effort is only half that of the Diesel locomotive. As regards starting up, it is not much better than the steam locomotive. In this field, the electric locomotive is incapable of making full use of the adhesive weight. To obtain starting powers similar to those of the Diesel locomotive, a more powerful electric locomotive has to be used.

But if the comparison is not to be taken

TABLE 1.

	Steam loco.	Diesel loco.
Power, H.P.	6 600 (ind.)	6 000 (engine)
Max. speed km/h	160	160
Weight in service, t	404	416
Axle arrangement	2D2	3 × (A1A-A1A)
Driving axles	4	12
Adhesive weight, t	125	312
Tractive effort on starting t	29.4	67.5

with caution, the curve characteristics of the three engines must be based on the same power — in this case, 2 000 HP at the wheel tread. At average speeds, if the power at the one hour rating and overload power be used, the electric locomotive is much superior. This superiority remains in the field of high speeds, even with the power at the one hour rating.

The great superiority of the Diesel locomotive in the field of low speeds makes it possible to consider whether it is economical to use an assisting locomotive.

SCHAEFER (9) stresses the dynamic importance of the adhesive weight of a locomotive by comparing in Table 1 the two powerful express locomotives of the New York Central R.R., the steam locomotive 2.D.2 h2 of 6 600 HP_i and the 3 × (A1A-A1A) Diesel-electric 6 000 HP locomotive.

The adhesive weight of the Diesel-electric locomotive, which is 2.5 times as great, and its starting effort which is 2.3 times as great, cannot fail to affect its acceleration capacity, although the steam locomotive is 10 % more powerful. In fact, the Diesel locomotive hauling 15 coaches has been able to attain an average acceleration $p_m = 0.133$ m/sec² between 0 and 55 km/h, whilst the steam locomotive only reached $p_m = 0.088$ m/sec².

2.08. Reserve of power and overload capacity.

The engine must have a suitable reserve of power. In the preceding paragraph, we dealt with this question in the case of the electric locomotive when speaking of the three power values. In the case of the steam locomotive, the power is determined by the three following magnitudes :

1) the power corresponding to the limit of adhesion, which has already been dealt with:

2) the cylinder power which, although constructional dimensions are fixed (cylinder bore, piston stroke, etc.) can vary between wide limits according to the regulation of the admission and pressure;

3) the power of the boiler which is still generally limited in Germany to the maximum at a rate of evaporation of D/H = 57 kg/m² of the heating surface of the boiler and per hour when calculating the timetables.

The fear of adverse repercussions on the cost of repairs, which is the essential reason for limiting the rate of evaporation to 57 kg/m² now seems to have been greatly reduced. Specialists think that rates of evaporation of 68 kg/m², in other words an increase of 20 % in the power of the boiler, is perfectly admissible, and these figures are already used as a basis for calculations, for example on the Reichsbahn and Bundesbahn. In our opinion, a momentary increase of 40 % can very well be required, consequently a value D/H = 80 kg/m². Trials of blast pipes carried out by the former Locomotive Testing Department of the Reichsbahn showed such an increase to be perfectly justifiable. The holder of the national award, WENDLER, even wanted to have a rate of evaporation in continuous working of 120 kg/m² on his locomotive

using pulverised coal. In this case, however, the effects on the condition of the steam (superheat) would have to be considered, of the quantity of vapourised water per square metre passing over the water surface in the boiler would have to be taken into account, as also the harmonisation of the power in the cylinders with a rate of evaporation in the boiler increased by more than 100 %.

2.09. High specific power.

The condition of increasing the speed and the acceleration can only be realised by increasing the specific engine power in HP/t of the total weight. What is the position in this respect with the three methods of traction ?

DRECHSLER (2) has considered the position on the Bundesbahn in detail and states that the specific power in the case of steam traction varies according to the type of service from 1.3 to 4.5 HP/t, with electric locomotives, from 2.6 to 7 HP/t and in the case of railcars, from 7.5 to 11 HP/t. This comparison clearly shows the advantage of electric traction over steam traction, with almost double the specific power. But it is also plain to see why Diesels should be used for the railcar traffic, both the fast and the light services, if the traffic worked by small railcars is to have this name.

2.10. Installation of high specific powers (HP/m^2 or HP/m^3, or again m^2/HP or m^3/HP).

When studying motor units of the three types of traction in question, the engineer is faced with the same heights and widths, imposed by the loading gauges I or II. In view of the fact that the admissible axle load must be considered practically identical, it is in the length of the vehicles that we can get the criterion as regards the installation of specific power in HP/m or m/HP.

In this connection, the steam locomotive is greatly handicapped by the thermodynamic cycle used, which necessitates the installation of a boiler. To have sufficient room for the water and steam and above all a firebox of sufficient size, both as regards the large and small tubes and the smokebox, the classic Stephenson boiler needs a voluminous boiler and the need for carrying sufficient stocks of water and coal means having a tender, which takes up a certain length. As a result, our steam locomotives are nearly 24 m long.

The most favoured engine is undoubtedly the present type of electric locomotive, which takes the necessary power from the contact line and does not need any bulky components to transmit it to the traction engines like the steam locomotive.

As far as the installation of the power is concerned, the Diesel locomotive occupies a place half way between the two others, the Diesel-electric system being most like the steam locomotive owing to the need for three power installations : the Diesel, the generator and the traction engines, whereas the Diesel-hydraulic system takes up much less space and consequently is most like an electric locomotive.

Table 2 shows, for a series of steam, Diesel and electric locomotives, the specific power in HP/m of the length of the engine.

Amongst the locomotives dealt with, it is possible to compare, according to the type of service and power, in passenger service for example, the BR 01, V 200 and E 44 locomotives, and in freight service the BR 42, V 188 and E 79 locomotives — in the case of the last named, as there was no appropriate comparative locomotive, recourse had to be made to a passenger locomotive. The comparison of the lengths per unit of power, in m/HP gives the following classification (the index D signifies the power in continuous rating, the index *i*, the indicated power) :

Express service	1. E. 44	5.3 m/1 000 HP_D
	2. V. 200	8.1 m/1 000 HP_D
	3. 01	10.7 m/1 000 HP_i
Freight service	1. E. 79	8 m/1 000 HP_D
	2. V. 188	11.9 m/1 000 HP_D
	3. 42	12.7 m/1 000 HP_i

TABLE 2. — **Installed power in H.P./m of length.**

	Steam locomotive				
Series	01	42	61	62	95
H.P./m	94	78	77	98	107
	Diesel locomotive				
Series	V 200	DE 060	140	188	200
H.P./m	67	107	97	84	124
	Electric locomotive				
Series	E. 19	E. 44	E. 52	E. 79	E. 95
H.P./m	299	188	132	124	157

The figures clearly show the superiority of the electric locomotive in the field of the design of the vehicle. It can house almost double the power of the steam locomotive in the available space; but the Diesel locomotive also gives more favourable figures than the steam locomotive.

2.11. Favourable weight per HP.

A modern index for the appreciation of the success of the design is the weight required per unit of power, i.e. the specified weight in kg/HP.

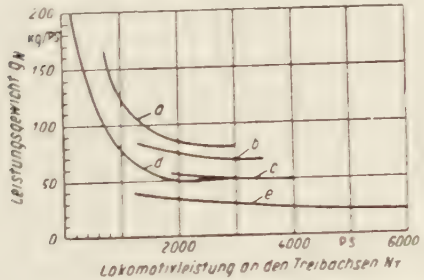


Fig. 4. — Weight per HP of European locomotive.

a = steam piston engine;
b = Diesel-electric locomotive;
c = Diesel-hydraulic locomotive;
d = gas turbine locomotives with electric transmission;
e = A.C. electric locomotives.

N. B. — *(Abscissae)* = power of the locomotive at driving axles. — *(Ordinates)* = weight per horse power.

As far back as 1952, KOTHER had studied the specific weights of European locomotives and gave them, with the reservation of a spread of 10 to 15 %, as shown in figure 4. The figure shows how the specific weight decreases as the power increases, as well as its absolute value for the different types of locomotives.

In a more detailed and wider study, also covering American locomotives, KRIENITZ confirmed this tendency and the absolute value of the specific weight as shown in the form of bands (fig. 5). The extraordinary amount of weight involved in the steam locomotive will be noted : on the average about 80 kg per HP; *Stephenson's* first locomotive, the Rocket, has a specific weight of 750 kg/HP. If the increase in power which is 210 times greater is compared with this reduction in weight of about 1/10, the evolution is characterised in a demonstrative way. The lowest specific weight is that of the electric locomotive, to be accurate the 16 2/3 Hz electric locomotive, where it is only 19 kg/HP; the first electric locomotive still weighed 350 kg/HP. Consequently in this case, the reduction of the weight by about 1/20 has been still more radical. Between the bands referring to the steam locomotive and the electric locomotive are the two variations of propulsion by Diesel, which come very close together at certain points. For example, the hydraulic transmission, currently used

in Germany, is luckily very close, owing to its specific weight, to the optima values of the electric locomotive. Perhaps, this is one of the reasons why American designers of Diesel locomotives are very interested in the hydraulic transmission. As they are less limited than we are from the point of view of axle loads, they have been able to use

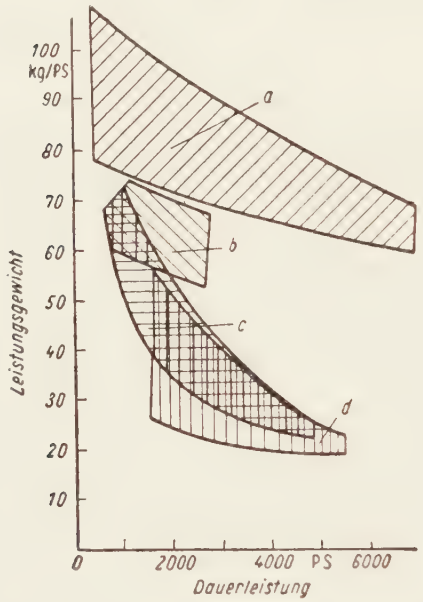


Fig. 5. — Weight per HP of steam locomotives, Diesel locomotives and electric locomotives.

a = steam locomotives;
b = Diesel-electric locomotives;
c = Diesel-hydraulic locomotives;
d = electric locomotives.

N. B. — *(Abscissae)* = continuous power. — *(Ordinates)* = weight per HP.

the electric drive so far, which is more elegant, and technically undoubtedly better as regards regulation. The band showing the specific weight in this case is very close to that of the steam locomotive. The American designers like to use slow Diesel engines in order to reduce as far as possible the lower limit of the speed, an advantage of Diesel traction that we have already mentioned.

In German designs of Diesel locomotives, on the average the specific weight is 35 kg/HP when the rake is heated from the locomotive by means of a special oil fired boiler, including the stock of oil and water; the specific weight of the Diesel locomotives falls to 31 kg/HP when there is no such heating boiler.

2.12. Simple division and distribution of the tractive effort.

In the classical rod drive of the steam locomotive, the tractive effort of the cylinders on each side of the locomotive is entirely transmitted through the intermediary of the piston head and the connecting rod and to the crank pin of the driving axle, and thence to the coupled axles through the coupling rod. This method of transmitting the tractive effort inevitably leads, as is well known, to considerable fatigue of the journal of the driving axle crank pin and the piston cross head gudgeon pin, and will always be a nuisance until some better way of lubricating the rod bearings is discovered. The idea of the replacing rod drive on locomotives by small steam engines driving the axles individually, as invented by HENSCHEL, has not succeeded in making itself adopted generally in spite of its well known advantages. In any case, the advantage of a better division and distribution of the tractive effort on electric and Diesel engines cannot be disputed.

On the Diesel locomotive, which, like the steam locomotive, carries with it to some extent its own power plant, the division of the power can be achieved at power plant level if, instead of using one large engine, several small engines are fitted, at the cost it is true of a certain loss in efficiency, and can be followed through the axle drives, according to the type of transmission of the tractive effort (Diesel-electric or Diesel-hydraulic engines). A particularly well adapted example of the division of the power is that of the Diesel railcar which has to some extent a multiple subdivision of the motive power and transmission.

2.13. Uniformity of the tractive effort.

The engine must give a tractive effort having a very high degree of uniformity,

which is not interrupted, even at transitions. With piston engines, the variation in pressure of the admission, expansion and compression curve of the diagram *PV* determines as a function of the piston movement the instantaneous piston effort, and through the final driving rod, the tangential efforts of pressure on the crank pin. The fluctuations in these tangential efforts of pressure are the greater, the fewer cylinders there are and the fewer the number of working strokes per revolution of the crank axle. As on the steam locomotive, there are usually two or at the most four cylinders acting per revolution, the irregularity of the tractive effort, which in addition acts directly, through the rods, on the periphery of the wheel in contact with the rail, is very considerable, as the profane can observe for himself when the train starts. Fluctuations in the tractive effort, which are manifest above all at low speeds and high tractive efforts, greatly interfer with the operation of starting trains in the case of steam locomotives. At higher speeds, the variations in the tractive effort are less marked, as the effect of the revolving masses then shows itself.

With Diesel traction, the subdivision of the moment of rotation by the arrangement of several groups of cylinders in line or in V (6 to 16 cylinders) makes it possible to compensate to a great extent the efforts of tangential pressure on the Diesel shaft, and to damp out almost completely any remaining variations when the power is transmitted to the driving wheels by means of the transmission used. Even with hydraulic drive, Diesels give an almost uniform tractive effort.

From the point of view of uniformity of torque, the electric drive of electric locomotives and electric transmission of units with Diesel engines, with their still greater subdivision, are the best forms of drive.

The importance attached to the elimination of irregularities in the tractive effort is shown by the trials carried out with a view to introducing propulsion by steam and gas turbine on locomotives. Some thirty gas turbine locomotives, already being built in series, are in service in the United States, and a whole series of other types in various countries.

As regards the interruption of the tractive effort, or its continuous regulation, the steam locomotive, in spite of its defects from the point of view of uniformity, is naturally able, thanks to the separate regulation of the wiredrawing and the admission by the lever of the regulator and the distribution, to adapt itself ideally over the whole range of speeds to the hyperbolic variation of the tractive effort/speed curve without an interruption of the tractive effort. The electric locomotive has to work by gradual scaling down of the voltage, which can be done without interrupting the tractive effort, but involves discontinuous variations in the tractive effort.

2.14. High specific mileages.

The engines of any traction system must have as great as possible a specific mileage per day and per year. The daily mileage of a locomotive is determined by the average running speed, and the time it is in service at the head of a train. The average running speed varies with the different types of trains. For a given type of train, provided it is not limited by any restrictions on the maximum speed, owing to the state of the line, it can be increased by the great acceleration capacity on starting with Diesels, and the greater power supplied at high speeds by Diesel and electric locomotives, as can be seen from the power curves.

The time in service at the head of train varies considerably with the three systems of traction. Whilst the electric locomotive, after finishing one journey, can always be used to make another, the Diesel locomotive has to fuel up in the end, and the steam locomotive may have to clean out its firebox and take in more fuel. The time required for this purpose varies very considerably according to the capacity of the installations and the number of locomotives to be dealt with at one and the same time; if there are any bottle-necks it can be very long. The steam locomotive is also very much handicapped compared with the other two types of locomotive by the necessity to wash out the boiler at greater or shorter

intervals determined by the quality of the water used, during which times, it is true, the periodic repairs and overhauls of the pistons and valves are also carried out.

This is why the locomotive mileages vary considerably from one to another of the three systems of traction. The Bundesbahn, for example, has established the following average mileages per day in service :

Steam locomotives	194 km	(express locomotives : 372 km)
Electric locomotives	294 km	(express locomotives : 434 km)
Diesel railcars	361 km	(maximum run : 667 km).

This maximum run of 667 km is effected by a 410 HP Diesel-electric railcar.

As it can be taken that the figures would be about the same if a Diesel locomotive were used, this gives a good criterion for the comparison of the three systems of traction from the point of view of the specific mileage. As moreover the period of use of a steam locomotive covers definitely fewer working days a year than its two competitors, owing to the need to wash out the boiler and carry out more important repairs and overhauls, the table showing the annual mileage is still more unfavourable for the steam locomotive.

SCHAEFER (9) gives for the United States, annual mileages with Diesel locomotives of 400 000 km (maximum 521 000 km) in passenger service and 200 to 220 000 km in freight service, whereas during the difficult conditions during the last world war, only 290 000 km in passenger service and 120 to 160 000 km a year in freight service were obtained. In Table 3, KRIENITZ gives some statistics which make it possible to appreciate the structure of transport in the United States, compared with that of the Bundesbahn, which explain and justify the lightning development of the use of Diesels.

The table gives an idea of the very low specific output of the lines of the vast rail network of the United States compared with Germany. The short distance traffic is mainly worked by motor or uban transport services, and only the long journeys are made by rail. In the case of freight traffic, the characteristic factors are the train loads, the transport distance and the quantities of goods carried. The low density of the various lines is due to the length of line in operation per 100 km² or per 10^6 inhabitants.

TABLE 3. **Comparison of the structure of the American railways and the Deutsche Bundesbahn.**

		American railways	*Deutsche Bundesbahn*
Length operated per 100 km²	km	4.4	12.1
Length operated per 10^6 inhabitants	km	2 470	623
Locomotives in service per km of line		0.106	0.367
Average wagon load	t	47.6	20.2
Freight train mileage	km	829.10^5	166.10^5
Freight mileage per km of line	km	2 440	5 500
Quantity of freight carried	t	$2\,729{,}4.10^5$	$249{,}2.10^5$
Average transport distance	km	365	186.4
Gross tonnage of a freight train	t	2 630	655
Passenger train mileage	km	$575{,}5.10^5$	$346{,}8.10^5$
Passenger mileage per km of line	km	1 690	11 550
Passengers carried		$486{,}2.10^5$	$1\,369{,}8.10^5$
Average length of journey	km	105.1	24.5
Passengers carried per km of lines		1 430	45 500

The use of heavy trains, and consequently at longer intervals, in the case of freight traffic as in the case of passenger traffic, explains the smaller number of locomotives per km of line, and creates the conditions needed for long locomotive runs and long specific runs. The Diesel locomotives can work up to 8 000 km before returning to their depot.

2.15. Constant availability.

Railway vehicles, like road vehicles and the units used by other forms of transport, must be constantly available to be able to cover any unexpected demands, or for use in case of any breakdown. If the maintenance of this reserve of stock is already a heavy financial charge on the service, it is increased when in order to assure such a reserve labour and materials costs have to be incurred, as is the case with steam. In this connection, the electric locomotive is ready for service immediately, and so is the Diesel if the cooling water for the Diesel engine can be quickly supplied by means of hot water during very cold weather and when the locomotive has been standing in the open.

In the case of the steam locomotive, a fire has to be kept up in the firebox during the whole period it is in reserve, which results in costs for labour and coal, and consumes some of the store of fuel and water on the locomotive which have to be estimated and made up before the locomotive goes into use. Trials of replacing the amount of heat lost by radiation from the locomotive boiler by supplying steam from a fixed boiler show that this situation can be improved; replacing the heat lost in this way is not however gratuitous, but merely more economical.

2.16. Able to run in both directions.

The condition of being equally convenient to use in both directions of running, which operating conditions now demand from any up-to-date railway vehicle, cannot be considered an exaggerated requirement. It would be unreasonable in the case of a road vehicle, boat or aeroplane, which can easily and simply change their direction of running at will. The use of a railway track robs the vehicle of some of its freedom of movement. In the case of vehicles so designed that normally they can only run in one direction, for example a steam locomotive with separate tender, it would therefore be necessary to provide numerous points at which they could be turned, in practice in fact in every depot, by such cumberous installations as triangles or loops or turntables, which are costing more and more to install and maintain as the weight and length of the units increase.

An operating department, which has the interests of economic progress in mind, will therefore require the designer of the vehicle to make it capable of running in either direction as required. On this point, the tramway has shown what can perfectly well be done with its motor units which have a driver's compartment at each end. The electric locomotive has followed the same path and the Diesel locomotive has always been so from the word go. There is moreover no difficulty in meeting this condition, the value of which from the operating point of view can hardly be exaggerated, both with hydraulic and electric drive. Nor must we overlook one special feature of Diesel traction which is much liked by the operating department and that is its suitability for telecontrol, which makes it possible to group several units together without additional labour costs. This is a possibility which is often made use of.

2.17. Simple and certain coupling or concentration of the source of power, of the motor, and of the driving machinery.

We have already dealt with the fact that a complicated cycle of operations are involved in steam locomotives, which do not represent a simple coupling up of the source of power, the engine and the driving gear. To do this, it is necessary that all the transformation of power takes place as it were through the shovel of the fireman, and according to the calorific power of the fuel used; this shovelling varies between very wide limits. However the transport work to be carried out in this way by the fireman exceeds the limits of what can be

asked of any man when the power of the locomotive increases. The remedy which consists in doubling the firemen, cannot be an economically satisfactory solution in this era of mechanisation.

From this point of view, the electric locomotive with its very simple picking up of the power supplied by the contact line, without any human physical effort, naturally represents the optimum solution of the coupling up of the source of power and the driving gear.

The Diesel locomotive, however, which it is true like the steam locomotive has to turn the power contained in the raw material into power on the vehicle itself, benefits by the advantage that the process of the transmission of power is much less complicated and more economical in this case from the power point of view.

2.18. Stability of running of the vehicle.

With the increase in speed, it has become essential for safe running, as well as for the running stability of the motor units, to look into the optimum arrangement of the mechanism and axles. The efforts made and numerous solutions put forward in the design of steam locomotives, and in the first years, in that of electric locomotives, have led, in the combinations of axle arrangements, in the damping out of the transverse stresses from the rail, and in the obtaining of sufficient centering efforts, to a whole series of detailed designs which prove the complication of the axle arrangements needed with rod drive to assure that the motor units shall have good running qualities; such names as GÖLSDORF, WEBB, KRAUSS-HELMHOLTZ, SCHWARZKOPFF-ECKHARDT, LOTTER, etc., will always be linked up with the history of the rod drive of locomotives.

And on the other hand, what simplifications have resulted to the builder from the adoption of two and three axled motor bogies, with their uncomplicated designs which are extremely favourable from the point of view of the technique of guiding. Trials made in 1955 by the S.N.C.F. with two fast BB 9004 and CC 7107 trial locomotives showed decisively the superiority of motor bogies for fast units, even from the point of view of the limitless possibilities of the power installed.

It can be admitted that the same applies to the Diesel locomotive.

2.19. Little wear on the permanent way.

Permanent way technicians, like the vehicle designers, note with the same satisfaction that there is also less wear of the track horizontally and, owing to the absence of periodic fluctuations in the axle load under the action of the rods and masses in equilibrium, also in the vertical direction. From this point of view, the Diesel locomotive probably must be credited with a still more uniform stressing of the track owing to the lesser importance of the non-suspended masses.

2.20. Simplicity of servicing, maintenance and overhaul.

Whoever having had experience of steam traction, has also been able to obtain experience in the field of traction by electric or Diesel engines, will certainly never think of pretending that the servicing, maintenance and overhaul conditions for steam locomotives are a simple matter. The complicated cycle by itself makes this impossible; this makes it necessary to have very specialised staff for the servicing, maintenance and overhaul, and involves very complete subdivision of the work to be done in the servicing, the maintenance in the depots and the overhauls in the large shops.

2.21. Cleanliness of working.

In the last place in the series of technical and operating conditions comes the idea of cleanliness. In this respect, it is not only the requirements of the passengers which are involved, but the needs of the driving and train staff. There is no doubt that all of them desire an improvement in present conditions, and the suppression of the nuisance due to deposits caused during the process of transforming the power used. From this point of view the advantage of Diesel and electric traction is obvious.

3. Economic conditions for an optimum traction system.

The economic conditions are just as important in the evaluation of a traction system as the operating conditions we have just dealt with.

The main condition which the question of economy sets a traction system is that of incurring as low as possible direct operating costs. By direct operating costs, we must understand the traction costs which consist of the seven factors given below.

3.1. Sinking fund charges for the motor units.

Under this heading, the cost of buying the stock fall very heavily. In its report the above mentioned Study Commission « Dieselschienenverkehr » gives, for example, in the case of express train services, the relations between price and weight given in Table 4, under conditions obtaining in 1950.

In the United States, for 5 000 to 6 000 HP locomotives, the following price proportions are obtained, in which it must be remembered that in view of the rapidity and extent with which Diesel locomotives have been put into service, the industry very soon was able to mass produce them :

Steam locomotives	100 %
Electric locomotives	137 %
Diesel locomotives	214 %

For the reasons stated, German conditions are much less favourable :

Steam locomotives	100 %
Electric locomotives	143 %
Diesel-hydraulic locomotives	233 %
Diesel-electric locomotives	260 %

The life of the three types of engines is in general uniformly taken as 35 years. The amount of the sinking fund charges is therefore proportional to the purchase price, and consequently at its highest in the case of Diesel traction and at its lowest in the case of steam traction.

3.2. Cost of repairing motor units in the depots and shops.

Under conditions obtaining in Western Germany, which have been used as the basis for the report to the study commission, the cost of repairing steam locomotives amounts to approximately 0.30 DM per km worked, if the locomotives are used for the maximum daily mileage per day in service of the locomotive, and amounts to almost double if they are only used for 25 % of the maximum mileage. These figures were obtained from reliable statistics kept over a long period of years on the Deutsche Bundesbahn.

In the same way, according to experience acquired over many years with electric traction, it is possible to expect a figure of 0.15 DM for repair costs per km run by a modern main line locomotive used to the maximum extent, although Fritzsche puts this figure at 0.20 DM and Kother even more cautiously at 0.25 DM per km worked. As regards Diesel locomotives, no figures based on prolonged experience of German conditions are yet available. If the working

TABLE 4. — **Ratio between weight and price.**

	P Price (1 000 DM)	G Weight (t)	N Power HP	Average price/kg $P_g \frac{P}{G}$ (DM/kg)	Price per HP $P_N \frac{P}{N_T}$ (DM/HP$_T$)	Weight per HP $G_N \frac{G}{N_T}$ (kg/HP$_T$)
a) Steam locomotive	350	171	2 240	2.05	156	76
b) Diesel-hydraulic locomotive	810	78	2 500	10.4	324	31
c) Diesel-electric locomotive	925	114	2 500	8.1	370	46
d) Electric locomotive	500	64	2 000	7.8	250	32

time of a Diesel engine hauling a train is taken as about 3 000 hours, with a life of 35 years, 12 % of the cost of the engine must be allowed for the cost of annual repairs. For the Diesel locomotive, excluding the Diesel engine, the cost of annual repairs amount to :

Express locomotive	5 %
Freight locomotive	2.3 %
Locomotives for stopping trains . . .	3.3 %

of the purchase price.

If for these groups average speeds of 75 km/h in express service, 35 km/h in freight service and 50 km/h in stopping services are used as a basis, when the engine has been working for 3 000 hours, the annual express service mileage will be 225 000 loc.-km, the annual freight mileage 105 000 loc.-km and the annual stopping train service 150 000 loc.-km, so that repair costs will amount to :

0.25 DM/loc-km run for the express Diesel locomotive;
0.28 DM/loc-km run for the freight Diesel locomotive; and
0.16 DM/loc-km run for the stopping train Diesel locomotive.

If in Western Germany not only electric traction but also Diesel traction already show a marked superiority in this respect over steam traction, which is heavily handicapped by the Stephenson boiler, this superiority, this time in the case of Diesel traction, becomes even more striking when we consider data relating to Diesel traction in the United States.

DORRER (10) quotes maintenance costs with traction by Diesel locomotives on the Erie Co., which only come to about one third of those for steam traction, the specific maintenance costs quoted by him being 11.3 cts/km for Diesel traction compared with 35.6 cts/km for steam traction. SCHAEFER (9) states that the cost of repairing Diesel locomotives is only 40 to 50 % of that of steam locomotives with a percentage of time out of service for repairs of 3 to 4 % and at the most 8 % for Diesel locomotives.

In interpreting these figures, it must not be forgotten, that on the one hand they refer to relatively new locomotives, and on the other that competitive interests are certainly involved. However, steam locomotives can never reach 96 to 97 % user like Diesel locomotives.

3.3 Costs for servicing the vehicles.

These costs are not proportional to the distances covered by the motor units. The study commission in their report gave figures of 10 to 48 DM per day in service.

3.4. Labour costs.

The costs of the engine crew are not calculated from the mileage run but as a function of the time, and in the most favourable case, 3.5 engine crews may be used daily. As the user of the vehicle diminishes, from the point of view of the mileage worked, costs do not fall off proportionately, because the time lost in the preparatory work and on return to the depot, movements to get to the head of the train or return to the depots, etc., becomes relatively higher. In the case of steam traction, two men are required (driver and fireman), while for electric and Diesel traction with safety devices only one man is needed. As the time for preparing for work and at the end of the run are also shorter with Diesel and electric traction, according to the investigation of the study commission, they can be taken as 45 % of the costs for traction by steam locomotives.

3.5. Cost of power at the motor unit.

In considering the cost of the power, account must naturally be taken of the energy output of the motor units, which varies very considerably. Figure 6 gives diagrams showing the distribution of energy for steam, Diesel and electric locomotives in their most favourable fields of use. The Diesel locomotive shows the highest overall output, 32 %, ratio of the useful power at the wheel tread to the thermal power contained in the fuel, taking as basis a thermal output of the Diesel engine of about 40 %, an output which the Diesel keeps to between wide variations of speed of rotation and load.

According to EICHELBERG and PFLAUM (8) an increase in the thermal efficiency of the Diesel can be expected in the near future,

raising it to 45 % thanks to very extensive supercharging. The overall thermal efficiency of the Diesel locomotive, which today amounts to 28 to 32 %, taking into account, mechanical, hydraulic or electrical transmission losses, will then be 32 to 36 %. In service, the economic output, taking into account variations in the load, under these conditions, will not fall below 28 to 32 %.

in the world, can never be more than 12 %, even in the future. In the processus of transforming power proper to the steam locomotive, it is not possible to improve the output of the boiler, which is 75 %, nor to reduce the losses of the steam engine, which amount to 60 %.

The situation is still more unfavourable if the power at the drawbar is taken as a

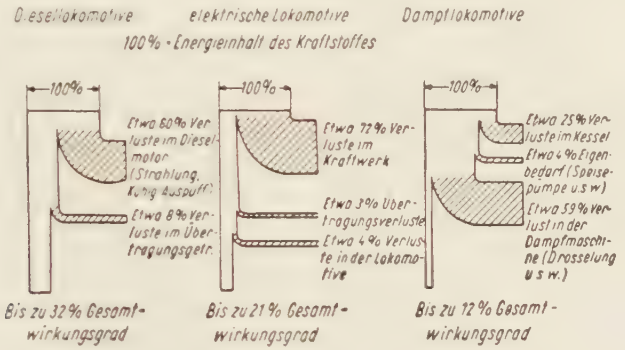


Fig. 6. — Power diagram.

N. B. — Diesellokomotive = Diesel locomotive. — Elektrische Lok. = electric locomotive. — Dampflokomotive = steam locomotive. — 100 % = Energieinhalt des Kraftstoffes = 100 % = power contained in the fuel. — Etwa 60 % Verluste... = about 60 % loss in the Diesel engine (radiation, exhaust, cooling). — Etwa 8 % Verluste... = about 8 % loss in transmission. — Bis zu 32 %... = overall efficiency, up to 32 %. — Etwa 72 %... = about 72 % loss in the power station. — Etwa 3 % Übertragungsverluste = about 3 % loss in transmission. — Etwa 4 % Verluste... = about 4 % loss on the locomotive. — Bis zu 21 %... = Overall efficiency up to 21 %. — Etwa 25 %... = about 25 % loss in the boiler. — Etwa 4 % Eigenbedarf = about 4 % of its own consumption (feed pump). — Etwa 59 % Verlust... = about 59 % loss in the steam engine (wiredrawing, etc.). — Bis zu 12 % = overall efficiency, up to 12%.

The overall thermal efficiency of the electric locomotive is about 30 % less than that of the Diesel locomotive, but it is still very high, and amounts to as much as 21 % when the power is supplied from a power station with an up-to-date steam turbine with condensation, and with the optimum user of both power station and locomotive. In general we can count on an overall efficiency of 15 to 20 % for the electric locomotive. If the current is supplied by hydraulic power stations, it increases, it is true to 50 %.

Here again, it is the steam locomotive which puts up the worst performances. Its overall efficiency, even with the best will

basis, as this is again reduced still further, according to the weight and axle arrangement, by the energy used by the locomotive for moving itself. As according to Kother (4), the weight of steam, Diesel and electric locomotives of say 3 000 HP have a ratio of about 234 t : 144 t : 84 t, so that in consequence the steam locomotive is nearly three times as heavy as an electric locomotive, the former will therefore need several times as much power to move itself as the electric locomotive.

For example, with the BR 39, the drawbar power even under the most favourable conditions is only 7.34 % of the power supplied, and 8.2 % with the BR 01; only

the locomotive which to date has given the lowest fuel consumption, the Krupp turbine locomotive (0.75 kg/HP$_e h$ of coal at 7 000 kcal/kg) has given the unique thermal efficiency at the drawbar of 10.14 % at its optimum speed of 80 km/h. The Diesel and electric locomotives, owing to their low weight and more favourable arrangement of the mechanism from the running point of view, undergo lower losses between the power at the tread and the power at the drawbar.

As for the actual cost of the power, this is determined by the specific power consumption for the different types of train, by the transport requirements in gross ton-km of the locomotives or the mileage of the railcars or mileage of the electric rail motor coaches, and by the costs of coal, fuel oil and electric power which vary to an extraordinary degree from one country to another. These affect the traction costs to such an extent that the choice of the system of traction is often decided as a function of their amount.

The variation is particularly great in the case of fuel oil because the different countries impose very different fiscal charges on petroleum products. In the case of the electric locomotive, the cost of the power at the pantograph corresponds to the cost of coal or Diesel oil on the locomotive. The former consists of the cost of current at the busbars of the power station, which depends on production costs, a supplement to cover the loss in transmission from the busbars of the power station and the pantograph and another intended to cover the annual costs of the transmission installations (transport lines, substations, contact lines). The price of current is influenced decisively by the load on the line which also determines whether this shall be single or double track, simply equipped with a contact line or in a very costly manner with a long distance transport line, substations and contact lines.

The load on the line is expressed by the annual consumption of power per km of line. In Germany, in the case of the secondary single lines, it comes to rather under 100 000 kWh, in Austria and Southern Germany, mostly double lines, to about 325 000 kWh, in the German Russian section, final arrangement, to about 450 000 kWh, in the United States, minimum for the installation, 500 000 kWh, and in the case of the Rhine-Ruhr project, with double and multiple track lines, on the average 900 000 kWh, with peaks of as much as 1 500 000 kWh on certain sections of line. Figure 7 shows the variation in the cost of current

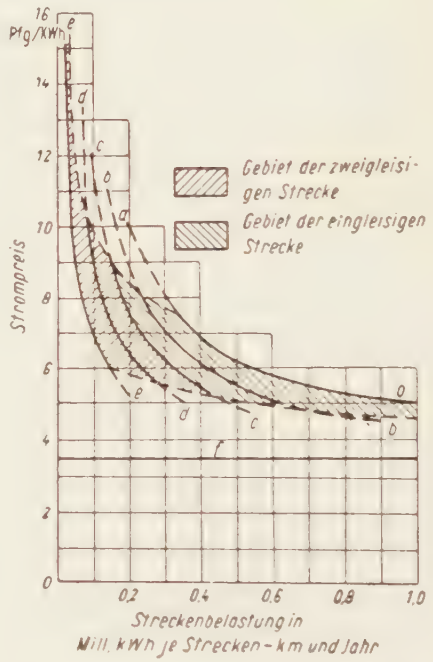


Fig. 7. — Cost of current at the pantograph.

a = double track line with carrying line, substation and contact line;

b = double track line with substation and contact line;

c = double track line with contact line or single track line with carrying line, substation and contact line;

d = single track line with substation and contact line;

e = single track line with contact line;

f = supposed cost of the current at the power station.

N. B. — Streckenbelastung in Mill. kWh... = load on the line in million kWh per km of line and per year. — Strompreis = cost of the current. — Gebiet der zweigleisigen Strecke = double track line section. — Gebiet der eingleisigen Strecke = single track line section.

at the pantograph as a function of the load on the line under the hypotheses that the cost at the power station is 3.5 Pf/kWh. The diagram, with the curves *a* to *e* characterising the equipment of the line, as well as the upper and lower limiting curves also show the relation between the type of equipment and the load on the line.

3.6. Cost of lubricating the motor units.

The cost of lubricants, which in practice can be considered as proportional to the mileage, are calculated from the mileage, specific consumption figures and the cost of lubricating oils. The figures for the specific consumption per 1 000 loc.-km run are extremely variable. In the case of steam locomotives in express service they amount to about 20 kg, in through freight service to 23 kg and in the services on secondary lines to 16 kg; they are therefore more than double the figures for the electric locomotive which uses 8.2 kg in express services, 10 kg in through freight service and 9.15 kg in service on the secondary lines. The explanation lies in the need to grease the bearings of the steam locomotive rods, as these are most inadequate in design; we have already criticised them above. There is no steam locomotive driver who does not suffer from seeing the oil from the lubricators of the rod bearings run over the running components, especially underneath the running board. It goes without saying that from the point of view of lubrication the steam locomotive is also handicapped by the fact that for reasons of weight, it is still necessary to use carrying axles, the number of which may be as much as four, and to provide up to five axles for the tender.

Like all units with Diesel engines, the locomotive uses an amount of lubricating oil equal to about 2 % of the fuel consumption, or about 25 kg per 1 000 loc.-km covered in normal express service.

The Diesel, a very perfected form of engine, is naturally more exigent from the point of view of the quality of lubricating; the electric locomotive, in this connection is much less exigent than its two competitors.

3.7. Cost of feed water supply.

Costs for the feed water only concern the steam locomotive, if we overlook the small amount of cooling water required by a Diesel locomotive. With a production of 7 kg of steam per kg of coal, and an average price of 0.25 DM/t, the cost of the feed water amounts to about 47.20 DM per million gross ton-km in express service.

To get a correct idea of the position, under conditions in Germany, and of the importance and variation of the cost of transport of the trains as a function of the daily mileage, to make it possible to compare such costs for steam traction, Diesel traction and electric traction, we have got out, on the basis of 1955 price levels, the cost of transport for a through freight train weighing 875 t, according to whether an IE series BR 50 locomotive with a boiler power of 1 625 HP, a B'B' Diesel-hydraulic locomotive with a 1 800 HP Diesel engine, or a Bo'Bo' electric locomotive with traction motors having a power of 1 500 HP continuous rating are used.

In the calculations of the cost of buying the units used as a basis for the sinking fund charges, we have taken the cost per kg now accepted by the Deutsche Bundesbahn in the case of steam locomotives for deliveries of the BR 83^{10} and 65^{10}, whilst the cost of purchasing Diesel and electric locomotives has been obtained from the price ratios given in the report of the study commission « Dieselschienenverkehr ». In the case of steam locomotives, we started with the real number out of service for repairs or in reserve in the Dresden Administrative area during the third and fourth quarters of 1955, whilst for the Diesel locomotives a figure of 20 % and of 15 % for the electric locomotives was adopted.

The determination of the cost of repairs in the main shops, only 15 % of which are a function of the mileage, was based on the average cost of the L 4, L 3 and L 2 repairs to the BR 50 in the repair shops. The cost of repairs at the depots, which are a function of the mileage, are also averages taken from the accounts of the Dresden Manage-

ment for the second to the fourth quarter of 1954. The average daily mileage of the type of train in question is some 240 km. Starting with the total repair costs per km for a steam locomotive determined in this way, the cost of repairing the Diesel and electric locomotives has been calculated, taking once again the ratios given in the report of the study commission.

Servicing costs have been estimated on the same hypotheses. The cost of the locomotive crews are based on the use of three crews; as the Diesel and electric locomotives need only one man, 50 % of the cost of driving steam locomotives with two men has been used as a basis.

Power costs have been estimated from the specific consumption figures given by the study commission for the corresponding type of service, for the price of coal now ruling, which consists of the price at the mine, the cost of transport (according to the Central Germany or Polish rates) and the cost of transhipment. Starting with the operating conditions already mentioned, the cost of power for the steam locomotives have been found, with different mixtures of coal as used, to be equal to the following values :

Coal (from Poland or Saxony) . . .	1 359 to 1 600	DM/million gross t/km (loco. included);
Lignite briquettes	785	DM/million gross t/km (loco. included);
Coal as it comes (large and fine) . .	1 256 to 1 303	DM/million gross t/km (loco. included);
Coal and lignite briquettes (ratio 1/1)	1 125 to 1 270	DM/million gross t/km (loco. included);
Coal and coal as it comes (ratio 1/1)	1 337 to 1.537	DM/million gross t/km (loco. included);
Lignite briquettes and coal as it comes (ratio 5/1)	821 to 825	DM/million gross t/km (loco. included).

The specific fuel costs for Diesel traction amount, with a supply cost of 617 DM/t for fuel oil, to 1 993 DM/million gross t/km, including the locomotive. The cost of electric current, excluding installation costs, amounts to 5.8 to 6 Dpf/kWh at the pantograph, and consequently the specific cost of current is 939 to 972 DM/million gross t/km.

The cost of lubricants has been determined by taking as a basis the specific consumption figures given in the report of the study commission and the oil prices now obtaining in Western Germany.

The different items of costs and the total traction costs of the 875 t gross through freight train with the three different methods of traction are shown in figures 8, 9 and 10. Figure 11 makes a comparison between the three kinds of traction by means of a graph in columns for the same train, with a daily mileage of 240 km.

The curves given in figure 12 show the most economical method of traction in each case. They bring out the absolute superiority of electric traction, excluding, it is true, the cost of equipping the line. In the comparison between the steam locomotive and Diesel locomotive, the superiority of the Diesel locomotive will be noted when it is question of small daily mileages. The Diesel locomotive is economically superior to the coal fired steam locomotive when it is question of mileages of less than 500 km a day.

The situation is however considerably modified in favour of the steam locomotive when lignite briquettes are used. Thanks to the initiative of our railwaymen in using lignite briquettes, the steam locomotive is economically superior when the mileage exceeds 110 km a day.

Thanks to the application of new progressive working methods, the steam locomotive under present conditions in Eastern Germany from the point of view of fuel is not only able to compete against the Diesel locomotive, but even to beat it in the field of large scale utilisation.

To sum up, it may be stated : The report of the study commission « Dieselschienenverkehr » has shown the net economic superiority, as indicated by the relative levels of traction costs, of electric traction

over the other two systems. But its adoption still depends as in the past on a sufficient load on the line in kWh/km of line. In the same way, traction by means of Diesel locomotives from the point of

Fig. 8 to 10. — Traction costs.

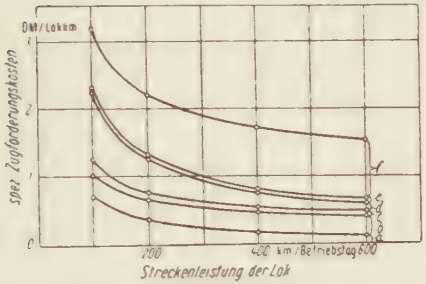


Fig. 8. — Traction costs for an 1 500 HP Bo'Bo' electric locomotive.

a = amortization; *d* = crew;
b = repairs; *e* = lubricating oil;
c = railway service; *f* = costs of current.

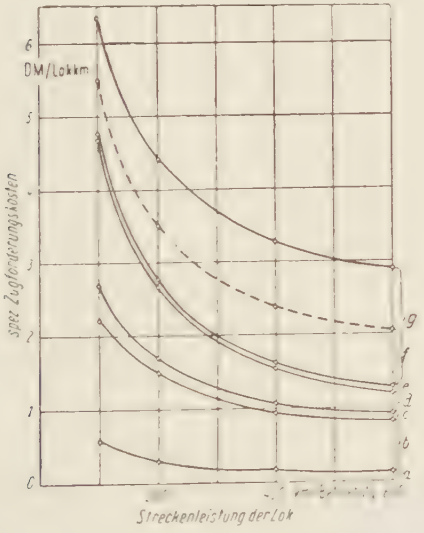


Fig. 9. — Traction costs for a BR 50 steam locomotive.

a = amortization; *e* = lubrificating oil and feed water;
b = repairs;
c = railway service; *f* = lignite briquettes;
d = crew; *g* = Polish coal broken up.

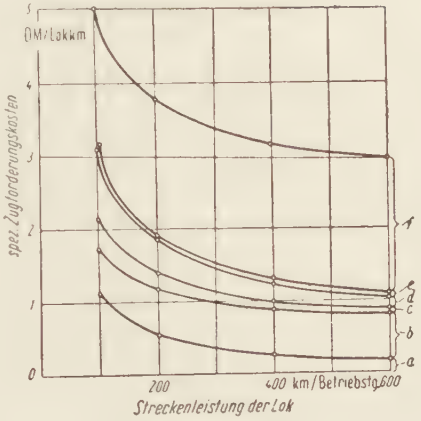


Fig. 10. — Traction costs for a 1 800 HP B'B' Diesel locomotive.

a = amortization; *d* = crew;
b = repairs; *e* = lubricating oil;
c = railway service; *f* = Diesel fuel.

N. B. — Strekenleistung der lok.-km/Betriebstg = loco-run in km per day of service.

view of costs, is cheaper than traction by steam locomotives, taking the present difference in price between coal and Diesel oil in Western Germany as a basis. In this comparison, therefore, steam traction is at the bottom.

In Eastern Germany, where price ratios are somewhat different, economic predominance must likewise be given to electric traction, provided the necessary preliminary conditions have been fulfilled.

In Eastern Germany, the Diesel locomotive is handicapped by the high cost of Diesel oil, and moreover the steam locomotive works under very economic conditions using lignite briquettes. It is to be expected that the establishment of the Kombinat « Black Pump » in the Senftenberg region, there will soon be a reduction in the cost of Diesel oil, which will make traction by Diesel locomotives economical in Eastern Germany as well.

It would however be a mistake to conclude, solely on the basis of the immediate operating costs, in other words the cost price of traction, that there is a justification or not for one system of traction. The position of this method of traction as

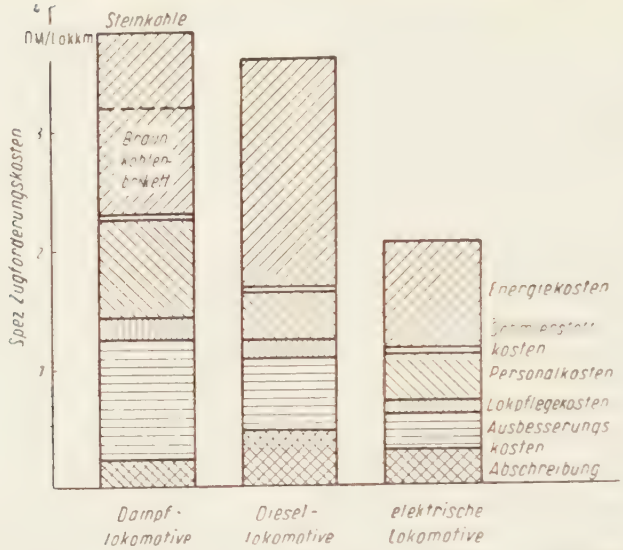


Fig. 11. — Comparison of the traction costs for a through freight train of 875 t, with a daily mileage of 240 km. for the three different methods of traction.

N. B. — Spez. Zugförderugskosten = specific traction costs. — Steinkohle = coal. — Braunkohlenbrikett = lignite briquettes. — Energiekosten = power costs. — Schmierstoffkosten = lubricating costs. — Personalkosten = crew costs. — Lokpflegekosten = servicing costs for the locomotive. — Ausbesserungskostn = repair costs. — Abschreibung = amortization.

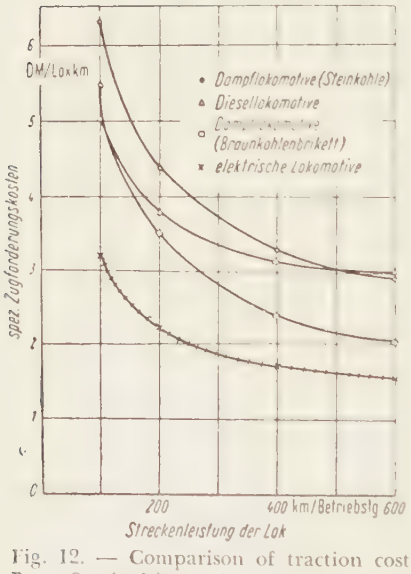


Fig. 12. — Comparison of traction costs.

N. B. — Streckenleistung der Lokomotive = mileage of the locomotive. — Spez. Zugförderungskosten = specific traction costs. — kb Betriebstag = km/day mileage.

regards technical and operating conditions must also be weighed in the balance. It is enough to say that in nearly all the 27 points enumerated above, the steam locomotive is more or less outdistanced by its competitors, the electric or Diesel locomotive — though it must be granted superiority from the point of view of elasticity and cost price — so that there is absolutely no doubt that traction by means of the « good old steam engine » cannot no longer be considered worthy of our age.

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[625 .23]

Intercommunication between coaches using rubber bellows,

by Dr.-Eng. MIELICH.

(*Spoor- en Tramwegen*, No. 26, December 20, 1956.)

For the last 60 years European railway coaches have been fitted with intercommunication systems using concertina type bellows.

In the case of international traffic, it is even laid down the coupling dimensions of concertina type bellows which must be adhered to. The concertina type bellows has certain drawbacks, such as for example its costly maintenance, the discomfort experienced in getting from one coach to the other, the difficulty of coupling it up especially in bad weather, and its poor heat insulation. For this reason, the possibility of designing some type of closed in intercommunication which would not suffer from these drawbacks has been for a long time the subject of investigations. It must also be possible to use the new type during the transition period while some of the present type of bellows are still in use.

The Deutsche Bundesbahn after long investigations has introduced a system of intercommunication for its internal services (fig. 1), which has none of the above drawbacks. About 1 800 four axled 26.4 m coaches as well as 3 500 other coaches used in suburban services have been equipped with this new type of bellows, and a further 1 500 coaches will be so equipped in the next few years. The rubber bellows were found very satisfactory. Only small repairs have been required and no complaints have been made. The wear is extremely small although they have already been in use for 3 to 6 years.

The rubber bellows has the following advantages compared with the concertina type :

1. With the rubber bellows, the distance between two coaches is reduced from 1 300 mm (D. B.) to 300 mm as it is possible for the body to partly overhang the buffers. In this way, the useful surface of the coach is increased by 2.6 m². The

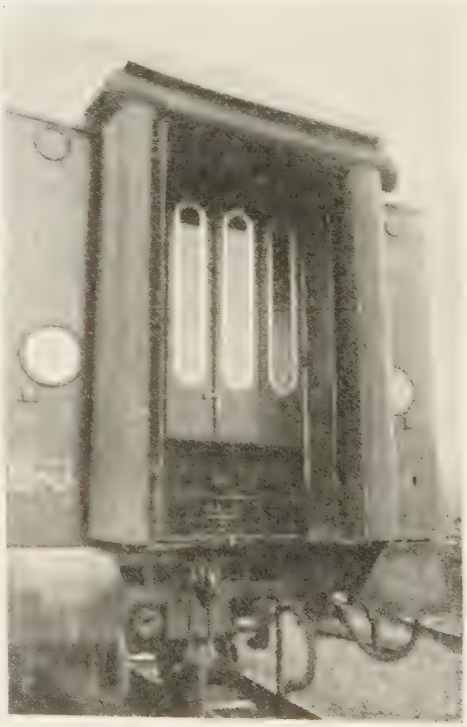

Fig. 1.

hatched portions of figure 2 represent this increased area.

2. Air resistance (at 140 km [87 miles]/h) is reduced by 28 % compared with the old rectangular coach shapes, as was already noted during researches carried out in 1938.

3. The difficulties of coupling up concertina type bellows, which cannot usually be done by one man, are completely removed.

5. The heat insulation of this type of intercommunication is good, as experience has proved so that the end vestibules of the two coaches can be heated at the same time under good conditions. As figure 5 shows the bellows still remain in contact when running through curves of 250 m radius.

6. It is possible to couple up this new system with the old type, if the vertical parts of the rubber bellows are fitted with

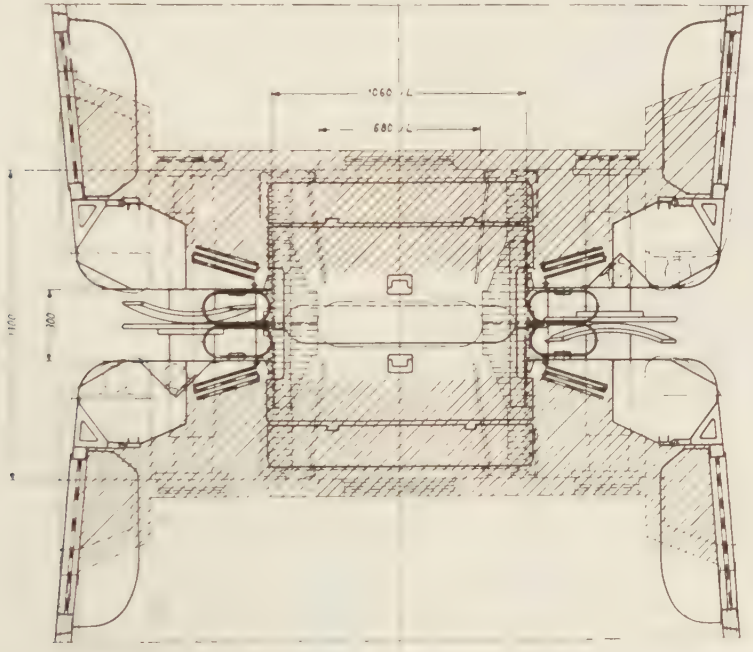

Fig. 2.

Air tightness is assured by the closeness of the two coaches. After coupling up, the footplates are put down (fig. 3).

4. The very convenient passage way, which is 1 060 mm wide, has not threshold or other obstacles. The smooth surfaces of the rubber bellows and the doors can easily be kept clean, which is not the case with the concertina type bellows (fig. 4).

airtight flanges which rest on the front end of the concertina bellows (fig. 6). Permanent contact is assured if the 6 fastening chains on the front end are fitted in the holes provided in the concertina type bellows. Screws prevent the hooks coming unfastened during the run. The chains can be stretched tight so that the rubber and concertina type bellows are well joined up (fig. 7). The system is made

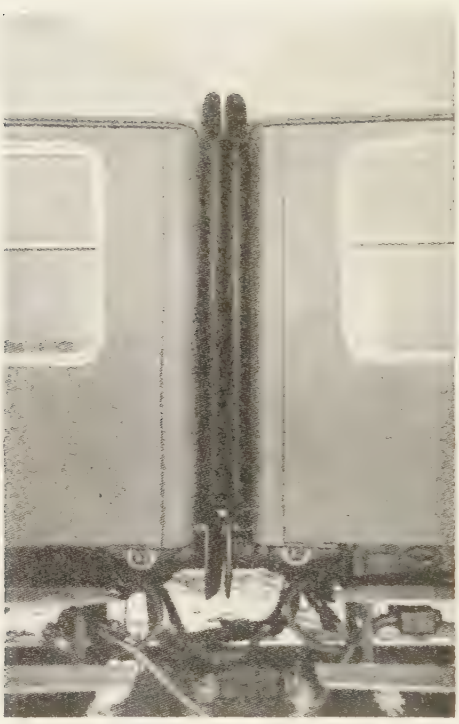

Fig. 3.

weatherproof by a gutter above the upper horizontal tube.

7. The purchase cost of the rubber bellows is in fact lower than that of the concertina type bellows which, as is well knows, have to be renewed every 2 to 3 years.

The maintenance costs for the rubber bellows are certainly lower and depend on the life of the rubber. The rubber bellows in use after 500 000 to 800 000 km and three years service have not shown any wear requiring appreciable repairs. The design enables the bellows to be reversed if necessary, i.e. they can be turned inside out.

8. Intercommunication by means of rubber bellows has been provided for a series of coaches with a driving compartment from which pushed trains can be driven. As a result, these coaches can also, when required, be used in ordinary trains. Extensive research, including measuring the air resistance of a pushed coach, has shown that this system does not increase the resistance of the leading coach of a train that is being pushed to any appreciable extent.

From the constructional point of view, it will be seen from the figures that the protection of the gangway includes two vertical rubber tubes closed in above by a horizontal tube. The 8 mm thick rubber is of 68 to 73 Shore hardness. Care must be taken to select a quality which does not age readily. The connection between the horizontal tube and the vertical tube must be an effective one because the vertical tubes roll on each other when there is relative lateral displacement of the buf-

Fig. 4.

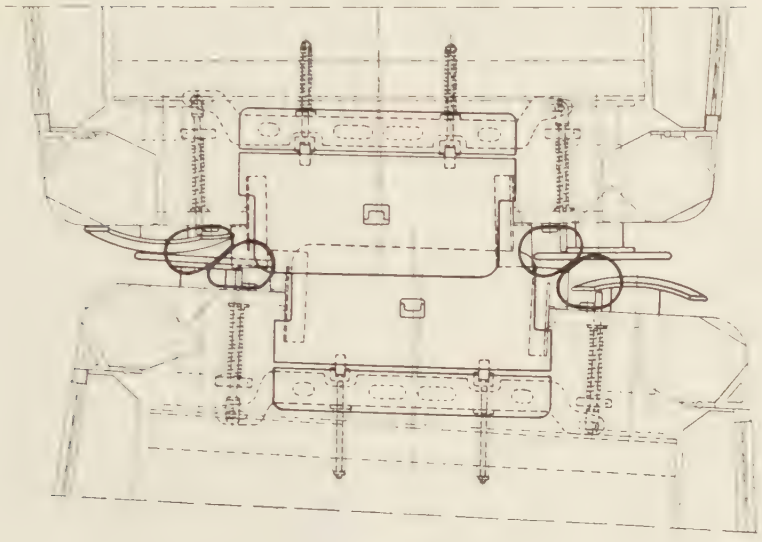

Fig. 5.

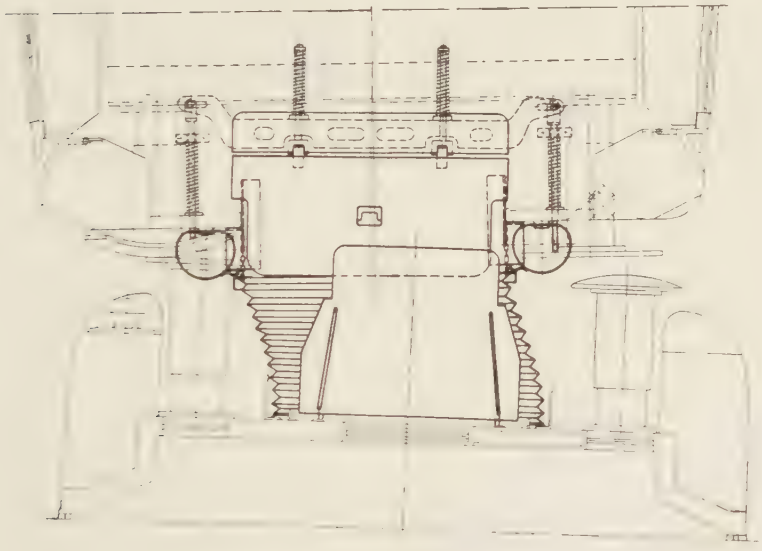

Fig. 6.

fers. In this way, they remain perfectly right. In order to assure when shunting the space known as « the Berne rectangle », a gap is left in the floor of the end of the coach which is covered by very wide fallplates (fig. 2 and 5). When the fallplate is raised up, the gangway is closed by a folding door with several leafs (fig. 2

and 4). Instead of a door, a metal shutter can be used. This shutter turns round the Berne rectangle, is balanced, and can easily be moved at the top and bottom. Since all the gangways remain open inside the train, such a shutter must not be operated by the passengers. This type of installation which is cheaper than multi-leaved doors, is used on the 3 500 suburban coaches of the D. B. mentioned above. The four axled coaches have a special design of gangway. So that the overlap of the two fallplates shall not exceed 2 × 75 mm, these gangways are guided through two bearings by plungers the springs of which can be compressed 110 mm. These bearings are fixed behind a crosspiece to which the fallplate is fastened by moveable hinges controlled by springs. The bearings are pressed up against the plungers by springs. The fallplates therefore follow the movements of the plungers. The elastic connection between the springs and the crosspiece is intended to avoid the raised-up gangway running back when the buffers are driven in, as otherwise the closed door would have to be put further back in the end of the coach, which was not desirable.

As the gangway is immobilised by a restraining arrangement, only the crosspiece moves when it encounters the springs of the hinges. The spaces left on the side of the fallplates are blanked off with fixed rubber components which in addition prevent the buffers from striking against the sharp edges of the front wall of the body.

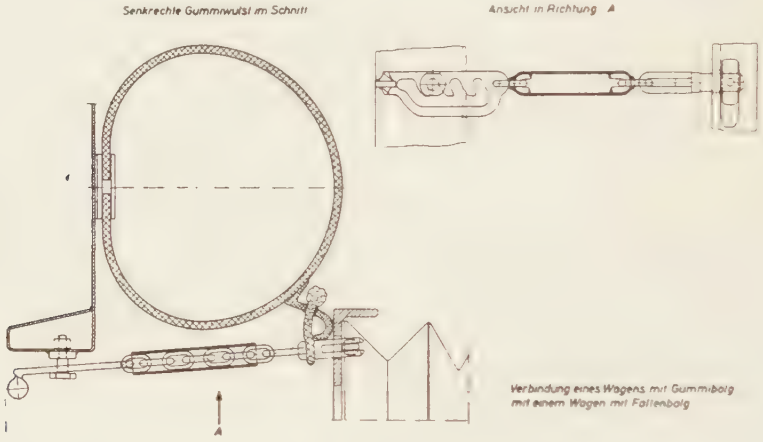

Fig. 7.

N. B. — Senkrechte Gummiwulst im Schnitt = section of a vertical rubber rim. — Ansicht in Richtung A = view in A direction. — Verbindung eines Wagens... = coupling of a carriage with rubber bellows to a carriage with concertina type bellows.

In the suburban coaches, the gangway is fixed directly to the frame, because the buffers of these coaches are never compressed more than 75 mm.

When the front end of the coach is constructed as described above, there is naturally no longer any room for the lamps. The tail lights both day and night are provided by two discs incorporated in the upper part of the body end. The red discs of these lights look grey and only show red when light is switched on. Emergency lighting is provided should the elec-

Fig. 8.

tric lighting fail. In order to meet the requirements of several administrations who fit the rear lights lower, there are two round colourless discs of 250 mm (fig. 1) beside the rubber tubes. If the vehicle when being used for international traffic has to have low rear lights, the coach is fitted with two red lamps with a cable and plug. These lamps can be hung inside the round windows and are supplied from a battery.

In view of the advantages of rubber bellows, it is proposed to fit them on all the old coaches. In view of the distance between the bodies, this sometimes necessitates a certain amount of sheeting (fig. 8). It is then possible to couple them up with other rubber bellows without any more to do. A certain number of these coaches are now undergoing trials.

To sum up, it can be stated that this new intercommunication system is from several points of view much better than the old concertina type of bellows. Passengers like them very much. As far as the operating is concerned, it is also a saving in labour. The shops prize its reduced vulnerability to damage, and the D. B. is proposing, in view of these advantages, to extend its use.

[625 .13 (44)]

Reconstruction of the bridge over the river Vienne at Châtellerault (France),

by J. Cholous,

Ingénieur à la Division Centrale des Ouvrages d'Art de la Société Nationale des Chemins de fer français.

(*Acier, Stahl, Steel*, No. 1, January 1957.)

The single-track railway line from Loudun to Châtellerault crosses, at the approaches to the last-named town, the river Vienne by means of a steel bridge consisting of two spans of 60 metres (197 ft.) length.

In August, 1944, the bridge was destroyed by war action. The steel deck, cut into several sections, fell into the river. The abutment on the Châtellerault side and the intermediate pier were completely destroyed and dislocated and had to be reconstructed with the exception of the foundations which had remained intact. The abutment on the Loudun side, which was much less affected, could be repaired.

Before it was possible to lift them, the sections of the bridge deck were carried away by a flood so that it was no longer possible to retrieve them. They had to be cut up in order to clear the river bed and remove the metal debris.

The reconstruction of the line was at first deferred in order to give priority to the more important lines, and it was not before 1947 that tenders could be invited for the reconstruction of the bridge over the Vienne.

The project envisaged an S.N.C.F. standard type top deck bridge with track laid on ballast and reinforced concrete flooring resting on the steel structure. The latter was to consist, essentially, of two continuous lattice girders with strong wind bracing. The design was based on the use of steel then held in stock by the S.N.C.F.

Unfortunately, for financial reasons, the work had to be deferred still further, and it was only in 1953 that the reconstruction of the bridge could again be taken in hand.

Meanwhile, the supplies position had changed. The steel originally earmarked for this purpose was no longer available so that a completely new project had to be worked out. In view of the experience meanwhile acquired with the reconstruction of similar bridges, it was decided to improve on the original project, which was otherwise retained in principle, by prestressing the concrete of the bridge floor and also using it to take part of the load carried by the bridge deck.

At this juncture, a lengthy parenthetical note is called for.

For a long time already, the railway administrations in general and the French Railways in particular have taken to using reinforced concrete bridge flooring because of its manifold advantages. Stress measurements carried out on composite steel and concrete bridges have revealed the considerable influence of the concrete slab on the load distribution. Even without special bonding, the concrete has a by no means negligible relief effect on the steel structure.

In the case of a bridge structure with continuous spans and top floor, the concrete is obviously subjected to compression stresses, owing to the load, near the middle of the spans and is therefore better able to resist the shrinkage stresses. In the vicinity of the intermediate supports, on the other hand, the stresses caused by the live load will increase the tendency of the concrete to cracking, and cracks in the vicinity of

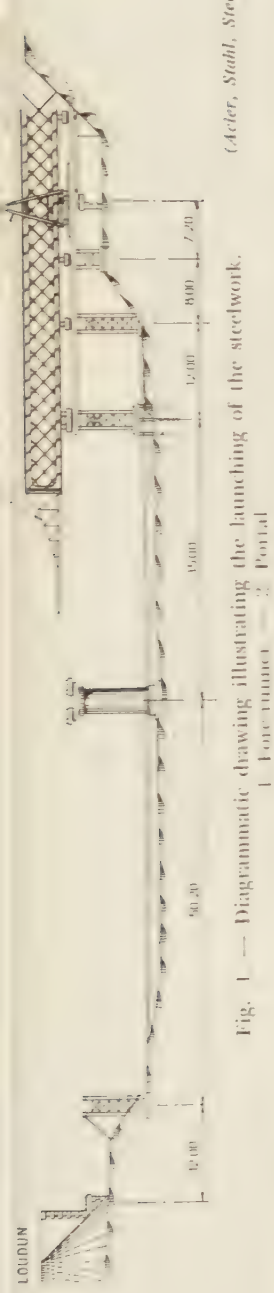

Fig. 1. — Diagrammatic drawing illustrating the launching of the steelwork.
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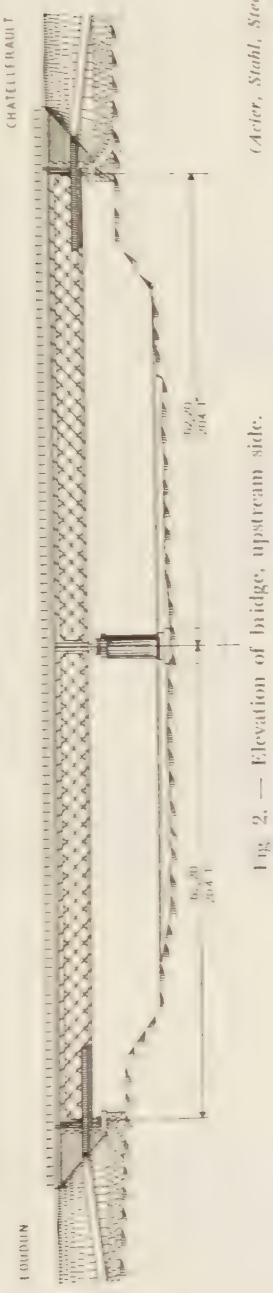

Fig. 2. — Elevation of bridge, upstream side.

the supports have in fact been observed at a number of bridges of this type.

To remedy this drawback, it is a logical idea to compress the concrete, during the construction, in such a way that it is never subjected to tensile forces in spite of the combined action of shrinkage and load. Numerous studies carried out on this subject, and structures actually built, especially abroad, show that the conventional prestressing methods by means of cables or the like entail certain complications. In particular, it is very difficult to obtain a good bonding between concrete slab and steel structure if it is desired to obtain this bonding only after the prestressing and shrinking of the concrete, which is the logical procedure if the operation is to be fully successful.

In the special case of the Châtellerault bridge, it was decided to obtain the prestressing effect by manipulating the level of the support. The principle of this method, which is entirely different from the one referred to above and has already been used, for a number of engineering structures of the French National Railways, is as follows :

After erection of the steelwork, the supports are adjusted in such a way as to cause, in the vicinity of the supports, sags similar to those caused by the live load.

The concrete slab is then cast, without special precautions, on the steel deck which is already provided with the bonding devices. After the concrete has set, the supports are restored to their former level which has the effect of introducing compression stresses into the concrete. The phasing of the level alterations or of the concreting can of course be varied in a number of ways according to the number of spans, the relative importance of the steelwork and the concrete slab, and the limit stresses. The method is very simple and, at the same time, very reliable, as the bonding between steel and concrete is effected before the prestressing, and the support reactions can be controlled, at any time, by means of hydraulic gear and compared with the theoretical reactions. It

Fig. 3. — The bridge after its destruction in 1944, seen from the right-bank upstream side.

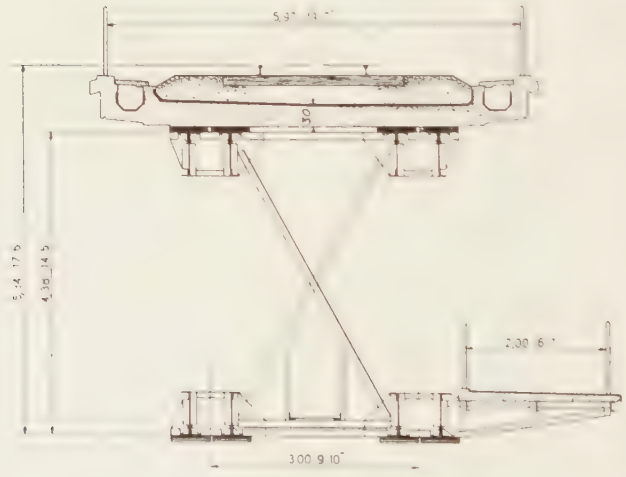

Fig. 4. — Cross section.

(Acier, Stahl, Steel.)

must however, be remembered that, while the prestressing has the effect of reducing the bending moments near the supports, it also has the effect of increasing them in the mid-span zones.

Altogether, the prestressing increases the weight of the steelwork by an amount which is about equal to the gain due to the participation of the concrete in the load bearing function (about 35 tons in the special case of the Châtellerault bridge).

each having a theoretical length of 62.20 metres. The girders are connected by cross-bracings spaced at intervals of 4.44 metres and by lower and upper longitudinal bracing. The latter is only required during erection, and is reduced to a minimum.

The girders, measuring 4.38 metres (14' 4") in height, have twin flanges of the « TT » type which are connected by four-fold lattice work. With this high degree of multiplicity, the distance between the panel

(Photograph : Studio David.)

Fig. 5. — The bridge during the launching operation.

The only advantage lies in the fact that the cracking tendency of the slab is eliminated. The better preservation of the structure and the reduction in maintenance costs are in themselves sufficient reasons to justify the operation.

After all these various modifications of the original project, the procedure actually followed at Châtellerault was as follows :

The steelwork, consisting of all-riveted steel of St 42 quality, is largely composed of two girders, continuous over two spans,

points is 2.22 metres (7'3") so that the sag of the top flange is small. The design is simplified as much as possible; there are practically no gusset plates or slit-and-tongue junctions, nor is there any vertical member except at the support.

The top flanges are provided with strong welded anchorages which ensure the bonding between steelwork and concrete. Their spacing varies as a function of the forces which must be transmitted between steel and concrete.

The concrete slab has an average thickness of 30 centimetres (1 ft.) and consists of normal reinforced concrete with a minimum crushing strength of 300 kg/cm² (admissible compression stress 84 kg/cm²). The reinforcement serves to provide the necessary resistance against transverse bending between the girders. As already mentioned, the track is ballasted.

The bridge structure is complemented by a service footway and by a public footbridge of 2 metres clear width on the upstream side. This footbridge itself consists of a reinforced concrete slab supported by steel brackets which are embedded in the bottom flange and connected by stringers.

The calculation shows that almost the whole of the couple due to this very eccentric load is absorbed by the torsion resistance of the bridge structure. The loads on the two main girders remain almost equal, and the two girders are of identical design.

The structure rests on the pier and abutments by means of supports of conventional design. The support shoes and plates are made of cast steel, the rollers of forged steel.

All the supports are movable except those on the abutment on the Châtellerault side which are designed to absorb the braking forces.

Apart from the main structure, the abutments also carry the reinforced concrete platforms which connect the footbridges with the approach ramps. The latter have a maximum gradient of 1 to 10 along the batter and comprise a small retaining wall and a floor of lightly reinforced concrete.

(Photograph : Studio David.)

Fig. 6. The new bridge at Châtellerault in the course of erection.

Construction.

Construction work commenced at the end of 1953 with the repair of the destroyed or damaged masonry.

The top parts of the pier and the abut-

ment on the Châtellerault side were reconstructed in vibrated gravel concrete with 250 kg of cement (250 315) and with carefully prepared shuttering so that no after-treatment was required. The abutment was given a light steel reinforcement so as to enable the whole mass of it to assist in absorbing the braking forces. The concreting of the uppermost part was deferred until the steelwork was in position so as not to impede the launching of the latter.

on the Châtellerault side. It would have been possible to use the embankment as erection platform and to lower the steelwork on to the supports after launching. For this purpose, however, it would have been necessary to provide special piers of 5 metres height, and it would have been difficult to ensure their stability on the narrow supporting structures. It appeared preferable to make a virtue of the necessity to strip and reconstruct the abutment,

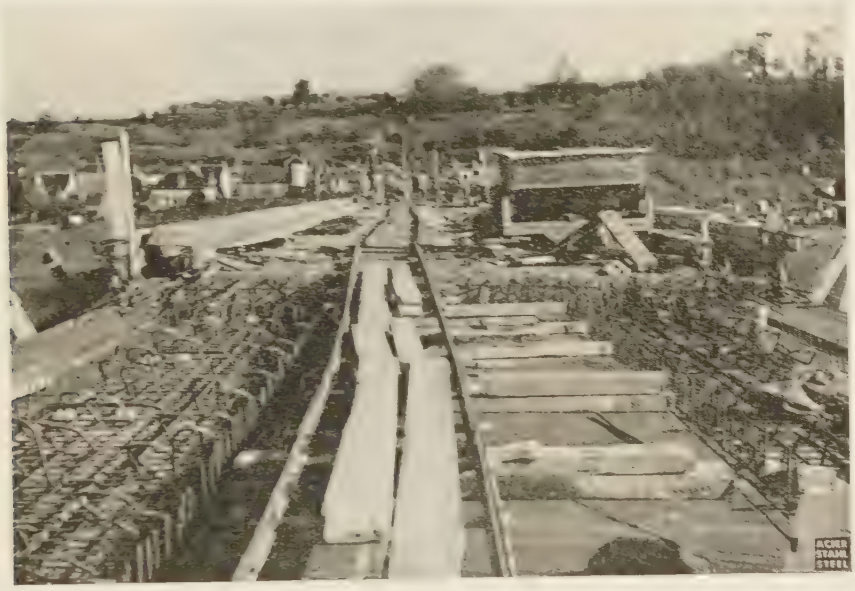

Fig. 7. — General view of the site

The abutment on the Loudun side was merely reconditioned and remodelled so as to take the new structure. All the bearings were provided with reinforced concrete tops which were lightly reinforced with iron bands.

Meanwhile, the steelwork was prepared at the workshop and the first parts of it arrived on the site in March, 1954.

The steelwork was to be pushed out across the river, and because of the local conditions, the erection had to take place for the purpose of erecting and launching the steelwork at a level close to its ultimate level, so that the lowering operation could be reduced to a minimum.

The erection platform was therefore prepared partly on the abutment, reconstructed up to the level of the under-girder, and partly on falsework which consisted of girders resting at one end on the abutment and at the other end on piles driven into the embankment and river bed. With these arrangements, and with the use of a fore-

(Photograph Studio David)

Fig. 1 — Bridge over the river Vienne at Châtellerault, shortly before completion.

runner of 15 metres length and supplementary piling on the Loudun bank, it was possible to avoid the need for any temporary strengthening of the steelwork during the launching.

However, the length of the platform was confined to about 40 metres so that the erection and launching work had to be carried out in several stages.

In October, 1954, the last launching operation was completed, and the steelwork rested on wedges which were so adjusted as to obtain the raising of the mid-river support by the 51 centimetres (1'8") required to obtain the necessary prestressing effect. At that stage, the ends resting on the abutments were each weighted down by 20 tons of ballast in order to obtain adequate support reactions. The concrete slab was then cast in symmetrically arranged stages, commencing at the ends.

When the concrete had set and hardened, the slab was prestressed. According to the calculations, it was sufficient to bring the supports back to their proper level by eliminating the rise of 51 centimetres at the pier. In the event, a beginning was made by lifting one of the abutment supports by 60 centimetres in order to avoid any tension in the slab and to obtain a first compression. Subsequently, the supports were brought back to their correct level by alternately lowering the supports on the pier and on the abutment.

The erection of the steelwork was carried out by a team of twelve men under the direction of a foreman.

The total number of rivets which had to be driven on the site was about 60 000.

After completion and testing, the bridge was put into operation on 17th January, 1955.

The work called for the use of 620 tons of steel for the steelwork, 500 cubic metres of mass concrete for the piers and abutments, and 400 m^3 of reinforced concrete for the bridge slab and supports.

The preparation and erection of the steelwork was in the hand of Etablissements Baudet Donon Roussel, whilst the masonry and concrete work had been entrusted to Entreprise Pierre & Pasquet.

[656 .225 (73)]

Piggyback — A billion Dollar market ?

(*Modern Railroads*, March 1957.)

One of the great imponderables in the railroad future is the question of the role piggyback may be expected to play. With practically no past history to lean upon for projecting future figures, the question is raised over and over, « Is piggyback really becoming a marriage of rail and highway modes of transportation ? »

This article raises many thought-provoking questions about the development and probable future of piggyback. It is based on a special report made by Transportation Facts, Inc., to amplify the information given in the RPI report of last November.

By 1965 U. S. railroads should be picking up a neat $ 1 billion gross annually from piggyback.

They should be handling from 5 to 6 million trailers a year, while the number of special flatcars in use should run about 50 000 of two-trailer capacity, or 75 000 of one-and-one half trailer capacity.

That $ 1 billion gross figure will be about 7 percent of total rail freight revenue, which should be better than $ 14 billion, including the $ 1 billion from piggyback.

These figures are based on a recent study by Transportation Facts, Inc., done at the request of The Rail-Trailer Co., Chicago.

Rail-Trailer was interested in the original study made by Transportation Facts, which was published in the R.P.I. report in November. It asked that the figures published in the R.P.I. report be amplified.

The result made a strong case for the motor common carrier type of piggyback, but it also pointed up the characteristics of all-rail piggyback as well.

For those who might feel that the supplemental study is a common carrier study, it should be pointed out that January figures substantiate to a high degree the figures set forth.

Despite the fact that January is a contra-seasonal month, The Rail Trailer Co. reported it the biggest month in the company's history.

More than 5 800 motor common-carrier trailers were handled by the Pennsylvania Railroad in January.

Pennsy officials point out that the total number of revenue trailers handled during January by the railroad (including all-rail piggyback) was approximately 7 500.

The supplemental study points out that for-hire truckers by 1965 may handle 134.4 billion ton-miles of freight for a gross of $ 10 billion. Add to that their share of piggyback and you get another $ 2.5 billion, making the expected total gross revenue for for-hire truckers $ 12.6 billion.

The railroad's $ 1 billion gross amounts to but eight percent of that figure.

In the R.P.I. report, Transportation Facts foresaw some 50 billion ton-miles of piggyback in the U. S. by 1965.

This would equal 5.7 percent of the total rail ton-miles in the country, and would equal 14.3 percent of the combined truck and piggyback ton-miles. It will amount to 22.4 percent of what Transportation Facts considers the competitive portion of the truck-trailer movement.

« Specifically », says Transportation Facts, « we foresee an average cargo load of 15 tons per loaded trailer, an average movement of 555 miles, and a utilization (for 75-ft. cars) yielding 11 to 13 trailer movements per month per car, with about nine of these loaded. »

What about all-rail piggyback, where the railroad owns its own fleet of trailers? Transportation Facts is not very optimistic on this score.

It feels that « the economies, sales promotion, and lower overhead benefits of handling common carrier truck fleets » are obvious.

« Because any shipper can hire or lease a truck trailer (or a container) more cheaply than a railroad could realistically supply one, we feel that the all-rail type of service will eventually account for less than 10 percent of total piggyback movement », says Richard A. RICE, Jr., President, Transportation Facts.

There are six reasons for this point of view :

— To make all-rail piggyback service feasible, railroads must purchase extra equipment and drum up new business.

— All-rail trailers will take vast new expenditures for equipment.

— Extra maintenance responsibility will be required.

— A specialized sales force will be needed.

— Depreciation will be high, since there seems to be little likelihood that a railroad owned « fleet » could get the same high daily utilization that common carrier truckers achieve.

— Common carrier trailers achieve a high load factor. Where rail-owned equipment would probably average 40 percent empties, the motor common carriers are accustomed to only 10 to 20 percent empties.

Actually, says Transportation Facts, common carrier piggyback for railroading means accommodation of an existing and fast-growing traffic pattern. Furthermore, this type of traffic most closely approximates that which the rails have « lost » during the recent years.

Advantages of three types of piggyback service.

Common carrier, all rail and container.

	Common Carrier	All Rail	Container
Traffic now moving	X		
Non-rail equipment in existence	X		
Greater rail revenue per load		X	X
Railroad needs no new loading machinery	X	X	
Railroad needs no new sales force	X		
Railroad undertakes no additional automotive maintenance	X		
Saving over 2 tons per unit by rail			X
Revenue to R.R. from empty return	X		
Probable 70%-90% units loaded	X		
Damage claims not R.R. responsibility	X		
Supply of containers not up to R.R.	X		
Railroad can rent special flatcars	X	X	X
Shipper can easily get container	X	?	
Railroad can cheaply farm out loading	X	X	
Minimum new railroad investment	X		
Present effective shipper relations	X		
Least likely to divert present R.R. freight	X		

Now let us backtrack a moment.

Just what is « piggyback » ?

« In the narrow sense of the word », says Transportation Facts, « piggyback is the *transporting of highway truck trailers by railroad flatcar in revenue freight service.* »

In a wider sense piggyback is the « ferrying » of one form of transportation by another.

Note, however, that the movement of freight in containers adaptable to trucks, trains or ships cannot be considered « piggyback », according to Transportation Facts.

The container, says that organization, is merely a large, all-weather form of packaging rather than a form of transportation. It must be loaded and unloaded with special new loading equipment and cannot be driven on or into the conveyance by its own components.

A question that is commonly asked about piggyback is, « How can a railroad haul truck trailers on flatcars at a rate cheaper than over-the-road costs ? »

Here's how it figures out :

— *Savings in crew and man-hours.* A train of 50 flatcars can accommodate 100 highway trailers, using five crewmen in place of 100 truck drivers. Driver cost for 100 trucks is $ 10 to $ 15 per mile, while freight train crew costs run between 75 c and $ 1.25 per mile — only one-tenth as much.

— *Savings in fuel consumption and expense.* Most tractor-trailer combinations are gasoline-powered and run about five miles per gallon. One hundred units consuming 20 gallons per mile at 25 c (including tax) per gallon, costs $ 5 per mile. A 50-car freight train uses about five gallons of Diesel fuel per mile. At 10 c per gallon, total cost per mile is 50 c — one-tenth as much.

— *Savings in vehicle maintenance expense.* Piggyback is estimated to save some 6 c per mile in maintenance (truck and trailer maintenance, including tyres, runs about 8 c per mile). Thus 100 trailers on a flatcar train may save $ 6 per mile of travel. Maintenance and repair cost of a large Diesel is about 50 c per mile; each flatcar costs about 2 c per mile. So a train-mile maintenance cost of $ 1.50 — one-fourth of trucks — is substituted.

— *Balance in vehicle depreciation.* Highway equipment on a 10-year life would place the annual depreciation of 100 $ 6 000 tractors at $ 60 000 per year. Piggyback may save three-fourths of this. The $ 400 000 Diesel and the 50 $ 10 000 flatcars are geared for a 20 to 30 year life and have a « real » depreciation of $ 45 000 or less per year. Since only one Diesel is needed for every two « trains », real net depreciation is even less.

The total of the expenses saved in the above ranges from 30 c to 35 c per mile, depending on the carrier and the area of the country.

What, then, can the motor carrier afford to pay the railroad to haul his trailers ? It must be remembered, says Transportation Facts, that costs upwards of $ 25 at each end of the line are incurred in getting the trailer to the train and loading it. This $ 50 expense amounts to 10 c per mile or more for an average 500-mile shipment.

Railroad piggyback rates per mile must average over 10 c per trailer mile less than the costs avoided in road haul.

In other words, « attractive » piggyback rates must be on the order of 20 c to 25 c to get the truckers' attention. Thus far, says Transportation Facts, railroad experience has indicated « just such a realistic pricing ».

It is possible that railroads may make more profit on piggyback than on general freight, Transportation Facts believes. There are three reasons for this :

— With common carrier piggyback, a far greater than normal percentage of cars will be loaded and damage costs eliminated.

— The movement of empty trailers is relatively small.

— Terminal and yard switching expenses, solicitation and accounting expenses are less.

Another factor to be considered is the high daily usage of piggyback equipment.

Present freight cars move in revenue service two to two and one-half hours daily at 15 to 20 m.p.h., covering 30 to 50 miles. Piggyback flatcars are expected to be used six hours daily at 20 to 30 m.p.h., or 150 miles daily. Such utilization with an average revenue of 35 c per mile (including some empties) could bring in revenue equal to $ 19 000 per year per flatcar.

Since present freight service revenue is equal to but $ 5 000 per class I freight car owned, it is well worth while to spend $ 12 000 for a 75-ft. flatcar against $ 8 000 for a regular freight car, notes Transportation Facts.

The organization warns, however, that labor costs for both rails and truckers are constantly rising and by 1965 a trailer-mile rate of 30 c for piggyback service can be both attractive and realistic, producing additional profits to both carriers.

New study by Model, Roland & Stone.

As for the « marriage » of rail and highway forms of transportation, Model, Roland & Stone, New York, in a recent study indicate that piggyback has already become an integral part of the nation's flow of material — a kind of commercial assembly line.

The study, entitled « The Trailer as a Shipping Container », gives five reasons for the continuing importance of piggyback in the production, processing and distribution of materials :

— The need of transporting component parts of an article from one part of a large manufacturing facility to another.

— The need of transporting highly processed commodities quickly. (See Modern Railroads, October 1956, p. 142.)

— The need of getting products of highly individualized design to the market as soon as possible.

— The need to avoid tieing up necessary capital in big inventories because of the constant change in consumer wants, design, etc.

— The need of synchronizing operations (between supplier and customer, for example) that may be far apart geographically.

The study points out that hitherto the growth of highway freight has been usually in shorter movements, combining the long-haul economy of the railroad with the direct and quick-service of the trailer.

« *Thus, for the first time, the shipper is offered the opportunity of long-haul economy with short-haul service* », it concludes.

Model, Roland & Stone feels that the role of piggyback will continue to grow in importance, and that the contribution to cost and time-saving in many different fields will more than justify the large investment which will ultimately have to be made.

« Thus », this investment counseling service says, « the trailer takes its place beside the more complex automation equipment in the high-level investment which has been sustaining the growing American economy. »

NEW BOOKS AND PUBLICATIONS.

[385 (09 (494)]

Les Chemins de fer Suisses après un siècle, 1847-1947. *(The Swiss Railways one century afterwards, 1847-1947)*.. — A commemorative work by the Federal Post Office and Railways Department, published in five volumes by the Federal Transport Office with the assistance of the Swiss Railways and many specialists under the editorship of René THIESSING and Maurice PASCHOUD.

First volume : **General. — History. — Finances. — Statistics. — Personnel.** — One volume (7 1/2 × 10 1/4 in.) of 622 pages, with figures and 5 maps. — Editions Delachaux & Niestlé, S.A., 4, rue de l'Hôpital, Neuchâtel (Switzerland) and 32, rue de Grenelle, Paris (VII[e]). (Price : 32 Swiss francs).

Two noteworthy events occurred in the middle of the last century in Switzerland.

In the political field, the 1848 Constitution gave birth to the Federal State. In the economic field, the railways came into being when the Zurich-Baden line was opened to traffic on the 1st August 1847. From that time, the country entered upon a period of increasing expansion.

The centenary was celebrated enthusiastically. But the Federal Office considered that in addition some commemorative work should be published depicting all the benefits which the nation owes to the railways.

The General Management of the Swiss Federal Railways and the Swiss Transport Union collaborated very willingly in the preparation of this work and numerous specialists gave them the benefit of their knowledge.

Whilst in no way derogating the value of the past, the authors wished above all to depict the railway as it is and operates today, and its future prospects.

Conceived on a very generous scale, the work is to consist of five volumes, as follows :

Volume I. — General. History. Finances. Statistics. Personnel.

Volume II. — Fixed installations of standard and narrow gauge railways.

Volume III. — Rolling stock of standard and narrow gauge railways.

Volume IV. — Administration and traffic of standard and narrow gauge railways.

Volume V. — Mountain railways and urban transport services.

In this first volume of a work which will cover a hundred years of progress, history has to be recapitulated. From this point of view the reader will not be disappointed. The hesitations at the beginning, the opposition of private interests, local peculiarities, financial questions, topographical obstacles, and many other factors bring out the merits of the pleiade of pioneers whose names will never be forgotten by posterity.

After the lines of the plains came those which crossed the mountains or ran through them thanks to the tunnels made.

The controversy on the construction and operation of the railway by the State or by private companies came to an end with the purchase of all the lines by the State.

To crown the work, electrification has conquered the whole system. A special chapter is devoted to the various changes of fortune and shows how this, in conjunction with the use of hydraulic power has favoured the national economy.

In the chapter *The Railway in the Life*

of the Nation, we are shown how public transport sustains and develops the activities of all classes of the populace. Its contribution to the national defence also merits recall and is justly appreciated.

A national tool of the first importance, the railway is affected financially by a great many factors. A series of technical and economic notes show the sollicitude of the State towards this aspect of the transport question.

Statistical methods have been perfected over the years so that they now give a clearer picture of the consistency and efficiency of the undertakings.

The final chapter deals with matters concerning the personnel : working conditions, training, safety, relations with the authorities, protection of material and moral interests.

The volume is copiously illustrated with artistic engravings reproducing documents of real historic value.

After this large scale frescoe, we await with interested and sympathetic curiosity the publication of the remaining volumes, which will take us still further into the technical realm of railway transport in Switzerland.

E. M.

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[656]

Dr René G. DUBOIS. — **Die Kartellierung im Verkehrswesen unter besonderer Berücksichtigung des Binnenverkehrs zu Wasser und zu Land** (*Cartels in transport undertakings, particularly in the case of inland transport by water and land*). — One volume (6 × 9 in.) of 208 pages. — 1956, Berne, Verlag Stämpfli & Co., Hallerstrasse, 7. (Price : 18.65 Swiss francs.)

This book was published under the auspices of the « Forschungsinstitut für Fremdenverkehr » of the University of Berne as Volume No. 49 of the Swiss Contributions to the scientific study of transport. The author explains in a lucid and alert style, which is also scientific and precise, how competition between transport undertakings has led them, like other industrial concerns, to study how to realise the harmonisation of demands and possibilities of transport when possibilities reach or exceed the point of saturation of demand; he submits the transport market to a rigorous study, and finally formulates, as a result of his researches, conclusions favouring the formation of cartels in transport undertakings.

The first chapter is devoted to an analytical study of the different forms of cartels (i.e. agreements made between members remaining completely independent, belonging to the same branch or branches of an industry with the object of conserving or increasing their receipts, or to stop their decline, by restricting the free play of the market), as well as the close reciprocal relationship between transport and the national economy, which has always led to State intervention and legislation.

The second chapter deals first of all with the actual economics of transport. Leaving aside the calculation of comparative costs, but examining the actual characteristics of the undertakings — their inflexibility owing to the structure of the investment, the public utility character of transport, the simultaneous existence of small and large transport undertakings, private and public undertakings — the author then goes on to the motive power behind the undertaking (profit, the greatest good of the community) : let us quote his opinion about this :

« The research of the greatest benefit for the community is however a principle in opposition to the selection based on private industry. It penetrates every industry affected by it in all its activities and prevents it from acting in a businesslike way

in the fullest meaning of the term, as to some extent the motive power for its actions, the struggle to make a profit, or at least to survive, is taken from it. The presence of factors seeking the common good is therefore far from being beyond suspicion. »

After dealing in passing with studies of sounding the market which should be done systematically by all transport undertakings as well as making efforts to specialise or adapt themselves to particular needs, the author studies the transport market itself and finds that « transport lends itself very well to the institution of cartels » and to explain carefully the forms taken by cartels and their effects on transport. He makes a distinction between cartels formed to obtain uniformity of costs, transport conditions, rates, regions, quotas or contingencies, rationalisation or reduction in the costs and those set up by the State, as well as their effects.

In a third chapter, the author traces the history of certain cartels. In some countries, where concessions have been granted to build parallel railway lines (Great Britain, United States), there are also cartels: likewise in the case of inland navigation on the great European rivers and lakes. The cartels covering transport on the Rhine (Duisbourg Freight Convention, Strasbourg Convention, the Swiss Pool) and the agreement as regards sharing the traffic between the Rhine shipowners and the railway (AVER agreement), and finally various agreements or projected agreements in Switzerland to regulate competition between railway and road are examined. (The « Schweizericher Güterverkehrsverband » (GVV) or « Swiss Union for freight transport » is the subject of a more detailed study.) Finally, the consequences of the European Coal and Steel Community are also examined.

The author draws various conclusions from his study of transport problems and the present position of transport undertakings, the excess of which now is leading to ruinous competition for the community, instead of the satisfactory state of affairs it could be. Looking for means to arrive at an appreciable reduction in the cost of transport, satisfy the demands of the transport undertakings and their customers, take into account the general economic aspect and policy of the State leading to a common social-political conception of those dealing with transport, he suggests the setting up of cartels which, whilst remaining on the collective plane, will enable their members — who remain free units — to satisfy their individual aspirations, improve their own equipment, increase their productivity, practise a sane policy as regards capital investment, business and prices, and finally put a certain amount of order in the transport market.

The establishment of such cartels would not take place without a certain amount of difficulty and inconvenience. The cartels should not aim at including all transport undertakings (for example, to a certain extent those carrying out their own transport), nor constitute an abuse of power, etc. The State could — and this should be the subject of an investigation to be undertaken — require transport undertakings to become members of cartels under certain conditions, keeping a careful watch to see that there is no abuse but not being itself a member of the cartel. As « the State is not an economic expert, either essentially or in fact. It is rather a protector of rights and the general welfare, which is more important than the general economy and should act as social equaliser ».

That is to say that far from having as its objective an artificial increase in prices, the cartel, according to Dr. R. Dubois, would be the best means under present conditions, through which customers, transport undertakings and the community would all benefit.

P. SCH.

[385 (09 (45)]

Uno Sguardo alle attività delle F. S. nell'Anno 1956 *Review of the activities of the Italian State Railways during the year 1956).* — Communicated by the General Management of the F. S. Extract from *Ingegneria Ferroviaria*, No. 2, February 1957. — One brochure (8 3/4 × 11 1/2 in.) of 48 pages, with 54 figures. — 1957, Roma, *Ingegneria Ferroviaria*, Piazza Crosse Rossa.

The year 1956 was characterised by the carrying out of the projected programme for modernising and increasing the power of the system. Certain sections of lines were restored to operation and certain of the bridges destroyed during the war finally rebuilt.

The foreword stresses the remarkable facts which are detailed in the following chapters on the different sections of the undertaking. Figures are also quoted showing that the traffic again exceeded that of the previous year and is much higher than that of the year 1938-39.

In the chapter called « Works and Buildings », mention is made of the strengthening of sections of lines, the rectification of layouts, and even the doubling of lines. Bridges have been renewed in order to take the higher loads and speeds. Station buildings have been modernised.

In the case of the fixed installations, electric traction gets the most mention. The rolling stock has also been increased by a large number of locomotives and railcars. Diesel traction has extended its field of application. New purchases and various improvements have added to and modernised the transport stock.

The security department has installed numerous central equipment of new types, in particular that used for telecontrol of the traffic in the Bologna network.

In the traffic department, new facilities have been offered to the public in the form of improvements to the timetables and interesting services.

The chapter devoted to the commercial department analyses the effects upon passenger traffic of the tariff reform resulting in two classes only. The passenger receipts increased, and the freight receipts to an even greater extent.

The rationalisation of the stores department assisted by the ever more extensive use of mecanography has made it possible to reduce administrative costs as well as the items in stores and their value.

The chapter devoted to the accounts comments on the financial results of the year 1955-56 compared with those of the previous year. The determination of costs for the different kinds of transport has been extended. Simplification in the accounts and statistics due to the use of electro-accounting machines with electronic perforation of cards has led to great economies.

The two following chapters show the importance attached by the management to the training and welfare of the staff, and the progress realised by the Research Department in an ever widening field.

The health service has developed various applications of modern methods and equipment for the benefit of the staff.

The recapitulative data, which end this substantial report, show the constitution of the railway and form a guide to the services rendered.

E. M.

[385 (05]

Jahrbuch des Eisenbahnwesens. Folge 7, 1956. *(Annual review of railway questions. Seventh Year, 1956).* Published by Berthold STUMPF. Frankfort-on-Main. — One volume (8 1/4 × 11 1/2 in.) of 278 pages, copiously illustrated. — 1956, Darmstadt, Carl Röhrig Verlag, Holzhofallee, 33*a*.

In his foreword, the author recalls the close links between transport and politics and economics, and states that the object of this publication is to contribute to the research into a better future.

The volume contains an editorial note and studies by various collaborators all well versed in railway questions.

The editorial note is devoted to the functioning and present position of the German Federal Railways during 1955. It deals with the traffic (on the increase), the services, the stock, and constructional work. The estimates for 1956 are optimistic as regards the balancing of the operating account, but road competition continues to weigh upon the position of the railway.

A study concerning electrification with single phase 15 000 V, 16 2/3 cycle current gives a description of the most interesting locomotives and motor coaches together with their performances. This system has fulfilled all expectations.

A study devoted to rails, gives notes on their profile, stresses due to rolling loads, manufacture, abnormal wear, long welded or even continuous rails.

In the large cities, the suburban services need suitable installations at the stations. This is the subject of an article which gives various possible solutions.

Under the title « Maritime stations » historical souvenirs of the Port of Bremen form an opportunity of stressing the importance of a rational arrangement of the installations and access sidings to maritime ports.

A study of the influence of the railway tariffs on the increasing competition of road transport shows the existing critical state of affairs which calls for a basic reorganisation of all transports.

The intervention of the European Coal and Steel Community in the tariffs for overland transport is the subject of a detailed study.

What will they think of our transport services in the year 2000? The author tries to reply to this question by anticipating what will be thought of the incoherencies of our times in the future.

A history of navigation on the Lake of Constance includes details about the technical and economic development of such transport and other closely connected undertakings.

A glance at the past recalls souvenirs of two personalities, who have played a great part in the railway world.

The volume ends with statistical information on the railways of the world : lengths of lines, density, electrification, traffic, operating coefficients.

E. M.

[385 (07 .2 (54)]

Annual report of the Railway Testing and Research Centre of the Railway Board, India (1955-56). Published by Director, Research, Railway Board, India. — One volume (6 × 9½ in.) of 117 pages, illustrated.

This report gives a complete review of the activities of the Testing and Research Department of the *Railway Board*, India, during the year 1955-1956.

The scope of the Centre is extensive and varied. It covers all questions of civil engineering and those relating to the rolling stock.

It has a great deal of equipment at its disposal including various test vehicles and three laboratories lavishly equipped with up-to-date apparatus. New acquisitions are also proposed.

In four successive chapters the author reports the research work undertaken and the results obtained. These researches are grouped under the following headings : civil engineering, mechanical, electrical, metallurgical and chemical.

Civil engineering includes experiments in connection with the superstructure of the track, studies of buildings including the foundations, tests on soil mechanics and the solving of special problems, the quality of mortars and the composition of concrete, and measuring the stresses which develop in the webs of metal beams.

In the mechanical group, without giving a complete list, we may mention the determination of the economic hauling power of various types of locomotives, the examination of the stability of locomotives and coaches, heating tests, measuring the lateral stresses exerted by the wheels of a *Pacific* locomotive on the rails on branch lines.

In the electrical chapter, a detailed description is given of an apparatus for measuring the reactions of the wheel flanges on the rails. An electrical cell is designed to measure the pressure of the soil in cuttings.

In the metallurgical and chemical section, the report mentions applications of methods of testing the materials and components used in the construction of locomotives, a technique for the internal treatment of the water in boilers, studies and trials of ordinary and special paints, and researches into welding electrodes.

The Testing and Research Department has drawn up in collaboration with other control organisations a programme covering an imposing list of problems to be solved.

These few details will suffice to show the effective aid being given to the various departments of the railway. Founded in 1952, the new department has made constant progress and further additions to its equipment are projected.

E. M.

[**621** .3 (03]

PIRAUX (H.), Ingénieur-électricien, Chargé de cours à l'Enseignement Technique. — **Dictionnaire Français-Anglais des termes relatifs à l'Electrotechnique, l'Electronique et aux applications connexes.** *(French-English Dictionary of terms used in connection with Electrotechnology, Electronics and similar subjects).*— One volume (6 1/4 × 9 1/2 in.) of 168 pages. — 1956, Paris (V[e]), Editions Eyrolles, 61, Boulevard Saint-Germain. (Prix : 960 French francs. — Postage and taxes included).

The continuous and rapid progress of electrotechnology have resulted in many new terms. Electronics are extending their field of application daily. New equipment means there must be a corresponding language to suit. And the exact meaning of the words is not always immediately clear.

The success of Mr. H. PIRAUX's English-French dictionary will be easily understood, especially as it is of interest to an ever increasing number of persons. The volume now being reviewed successfully completes the former one.

In fact, it was a more difficult task. It is easier to translate into one's own language than into a foreign language, and in this case there is also the question of a very special vocabulary.

The author, however, owing to his job and the work in which he participates was able to undertake this task with confidence.

In addition, he had recourse to a valuable source, the anglo-saxon words agreeing with the recommendations of the American Standard Association and the British Standard Association.

As a result, it is possible to give several translations of a phrase, with different shades of meaning, or according to the tendency in question. This explains why there are 20 000 English expressions for the 10 000 French expressions in the dictionary.

Of the many specialist subjects covered by the work we will only mention the most characteristic in our opinion : nuclear physics, optics, acoustics, radar, radio, and television.

In the field of scientific and technical literature, this dictionary will be of the greatest service to research workers, engineers, and technicians, especially English-speaking ones.

E. M.

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